**IEEE P802.19**
Wireless Coexistence Working Group

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# 7 Coexistence mechanisms and algorithms

## 7.1 General description

Coexistence mechanisms and algorithms shall enable coexistence among dissimilar or independently operated TVBD networks and dissimilar TVBDs. There are two coexistence problems to be solved related to TV channel use. One is how to allocate a proper operating channel to each TVBD or TVBD network regarding its neighbor TVBD or TVBD network. The other is how to share the same channel if two or more TVBDs or TVBD networks have the same operating channel. Regarding this, two mechanisms and algorithms are considered as the following;

- Operating channel allocation mechanism and algorithm
- Co-channel sharing mechanism and algorithm

#### 7.1.1.1 Maintaining channel availability information

The CM shall maintain the status of the TV channels available for TVBD operation according to the policies and rules established by the regulation. The CM shall obtain information on the TV channel status with respect to the presence of incumbents and other neighbor CMs in its location and it shall use this information as input for its decisions for channel selection, channel management, coexistence decision making, and etc.

To maintain the status of the channels availability, the CM shall be able to collect and fuse information from the following sources:

— TVWS database

— CDIS

— Neighbor CMs

— Measurement report from CE

The channel availability information shall be defined during the initialization of CM and it shall be periodically updated during the operation of CM.

#### 7.1.1.2 Channel classification and selection

In order to start operation of TVBD networks or devices, CM shall select and assign a proper operating channel for TVBD to mitigate coexistence problems among TVBDs. A proper operating channel shall be selected from one of allowed channels. According to a regulation allowed and disallowed channels that may be used by TVBD networks or devices at their location shall be given by TVWS database.

Status of given allowed channels will be dynamically changed based on incumbent activities, activities of other TVBD networks or devices, relocation of TVBDs, etc. To facilitate coexistence between 802.19.1 compliant TVBD networks or devices, the CM shall know status of TV channels at a given location such as:

— Which channel is available for TVBDs or networks

— Which channel is disallowed by regulation, or by the request of incumbents

— Which channel should be protected due to current incumbent activity

— Which channel should be restricted with limitations in order to use by TVBDs or networks

— Which channel is already being used by other TVBDs or networks

— Etc.

TV Channels for 802.19.1 logical entities are classified as the following 8 channels;

— Disallowed channels
— Allowed channels
— Available channels
— Protected channels
— Restricted channels
— Unclassified channels
— Operating channels
— Coexistent channels

The disallowed set is a set of channels disallowed for any TVBDs or networks by regulation, or by the request of incumbents. It should be provided by TVWS database and will be updated if necessary For example, in the U.S. TV channel 3, 4, and 37 are disallowed by regulation. Also a TV channel registered at TVWS database by a licensed wireless microphone is disallowed for any TVBDs or TVDB networks.

The allowed set is a set of channels allowed for TVBDs or networks. It should be provided by TVWS database and will be updated if necessary. All TVBDs or TVBD networks should first obtain a list of the allowed channels before their operating over TV channels.

The available set is a set of free channels available for TVBDs or TVBD networks.

The restricted set is a set of channels restricted to use with limitations due to regulation. It can be used by TVBDs or TVBD networks under limited conditions predefined by regulation. For example, in the U.S. a portable/personal TVBD can use “the first adjacent channel of the incumbent activating channel” with limited transmit power (≤ 40mW EIRP) by FCC regulation. Also in the U.S. channel 36 and 38 need more stringent emission mask to protect incumbents in channel 37 by FCC regulation.

The protected set is a set of channels to be protected due to incumbent activity. It cannot be used by any TVBDs or TVBD networks.

The unclassified set is a set of channels has not been classified as one of listed above three sets.

The operating set is a set of operating channels being used by one TVBD or TVBD network. It can be selected from available set or restricted set. If each TVBD or TVBD network has its own operating channel, spectrum etiquette with FDM (frequency division multiplexing) is achievable.

The coexistent set is a set of channels being shared by two or more TVBD networks. If two or more TVBDs or TVBD networks compete for the same channel, spectrum etiquette with FDM is not achievable.

Operating channels or coexistent channels shall be selected only from available channels or restricted channels.

Figure 2 shows hierarchical structure of TV channels. Allowed channels informed from TVWS database are further classified into the following categories:

— Available channels
— Restricted channels
— Protected channels
— Unclassified channels

Figure 3 shows Venn diagram of TV channels to demonstrate relationship among TV channels. The disallowed set is a subset of a TV channel set. It is also a complementary set of the allowed set. The allowed set is a subset of a TV channel set. It is also a complementary set of the disallowed set. The Available/Restricted/Protected/Unclassified set is a subset of the allowed set. Two different channel sets are a complementary set each other. The operating set is a subset of the available set or the restricted set or union of both. It is also a subset of a complementary set of the coexistent set. The coexistent set is a subset of the operating set.

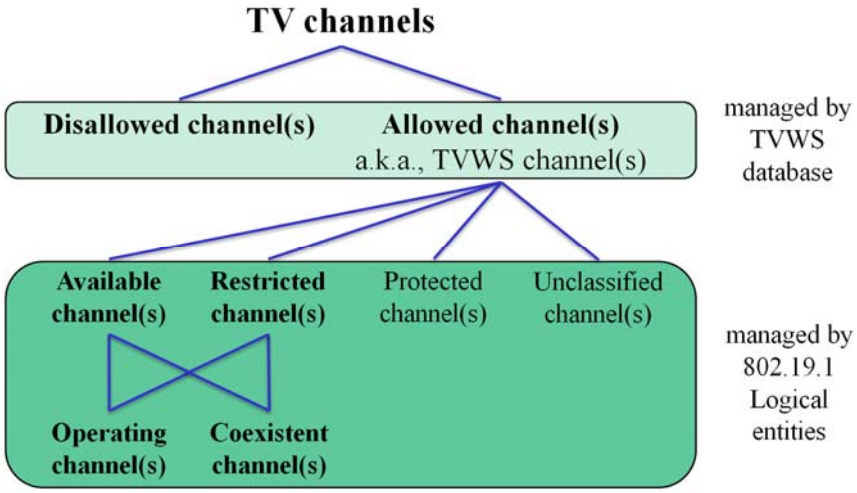


**Figure 1 Hierarchy of TV Channels**

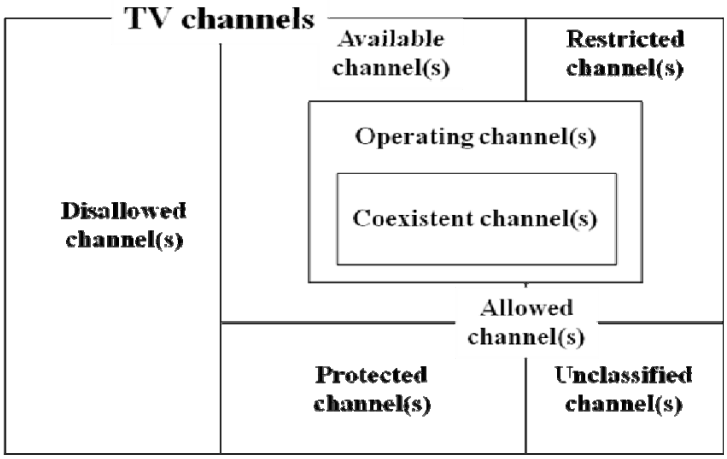


**Figure 2 Venn diagram of TV channels**

#### 7.1.1.3 Channel set transition diagram

The transition diagram consists of 6 states and 11 events. The 6 states are defined in Section 4.2.2.2. The disallowed and allowed channels are omitted in this transition diagram because those channels are classified by TVWS database and the sum of available, restricted, protected, unclassified, operating, and coexistent channels is equal to the allowed channels. Possible events for each state transition are defined as follows:

— Event 1: If the channel already being used by one TVWS system is assigned to other TVWS system(s) so that two or more TVWS systems use the same channel as an operating channel

— Event 2: If the channel is released by other TVWS systems so that the channel is being used by only one TVWS system

— Event 3: If the channel is released and not be used by any TVWS systems due to the completion of its usage

— Event 4: If the channel is assigned to one TVWS system and not shared by any other TVWS systems

— Event 5: If the channel is assigned to two or more TVWS systems at the same time

— Event 6: If an incumbent activity has been informed on the channel

— Event 7: If the channel temporarily satisfies the condition that requires its usage with limitations due to regulation, e.g., in the U.S. if an incumbent activity has been informed on the channel (F), the first adjacent channel (F±1) can be used by only a portable/personal TVBD with limited transmit power, say 100mW EIRP

— Event 8: If the channel is released by an incumbent due to the completion of its usage

— Event 9: If the channel is exempted from its temporary restriction and free to use without limitation, e.g., in the U.S. if the channel is released by the incumbent on the channel (F) due to the completion of its usage, the first adjacent channel (F±1) can be used by any TVBDs and networks

— Event 10: If the channel is not occupied by an incumbent or any TVWS systems

— Event 11: If the channel is not classified or updated within the predefined time expiration

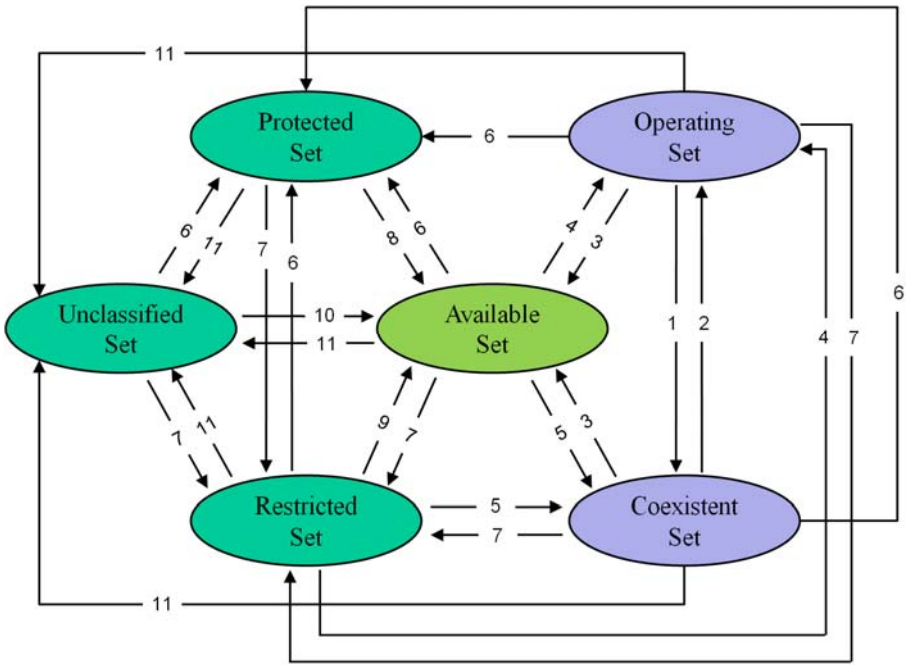


**Figure 3 Channel set transition diagram**

The channel set transition matrix is defined as depicted in Table 1. Each row specifies the state transition due to each event. Each column specifies state transition due to the events in each row for a particular current state. A blank cell within the transition matrix implies that either the specific event cannot or should not occur within that state. And if the event does occur, the CM shall ignore it. For example, the protected channel cannot directly transit to operating channel. Therefore, there is no operating channel in the first column (i.e., operating column).

**Table 1 Channel set transition matrix**

| State / Event | Operating | Coexistent | Available | Protected | Restricted | Unclassified |
|---|---|---|---|---|---|---|
| Event 1 | Coexistent | | | | | |
| Event 2 | | Operating | | | | |
| Event 3 | Available | Available | | | | |
| Event 4 | | | Operating | | Operating | |
| Event 5 | | | Coexistent | | Coexistent | |
| Event 6 | Protected | Protected | Protected | | Protected | Protected |
| Event 7 | Restricted | Restricted | Restricted | Restricted | | Restricted |
| Event 8 | | | | Available | | |
| Event 9 | | | | | Available | |
| Event 10 | | | | | | Available |
| Event 11 | Unclassified | Unclassified | Unclassified | Unclassified | Unclassified | |

## 7.2 Operating channel allocation mechanism and algorithm

After the interface setup as defined in section 6.1 has been done between two entities, each entity starts its operating stage. Each entity at operating stage is described by a number of designated procedures and events that triggers them. During its operating stage, CM, CE, and CDIS shall interactively operate to allocate an operating channel to each TVBD or TVBD network.

### 7.2.1 CM Operation

Figure 1 describes coexistence manger operating procedures that define a specific event and designated procedure triggered by it. At first the CM shall conduct channel classification to prepare channel allocation to its registered CEs. After that, the CM shall perform channel allocation based on channel classification and other aspects such as TVWS DB update, registered CE discovery update, neighbor CM discovery update, and registered CE's channel move request and so on. Main operating procedures of the CM consist of two parts: Channel classification and channel allocation. Including these, operating procedures of coexistence manager are as follows:

- CM_Channel_Classification
- CM_Channel_Allocation
- CM_TVWS_Channel_Update
- CM_Registered_CE_Discovery
- CM_Registered_CE_Discovery_Update
- CM_Neighbor_CM_Discovery
- CM_Neighbor_CM_Discovery_Update
- CM_Initiate_Registered_CE_Channel_Move
- CM_Initiate_Channel_Reallocation

- CM_Channel_Identification
- CM_Inform_Event

The procedure CM_Channel_Classification is triggered if flag 'Initiate_Channel_Classification' is set to be 1. This flag is set to be 1 if the CM has been initialized after power on or TVWS channels from TVWS DB have been updated. As depicted in figure 2, the CM firstly executes the procedure CM_Registered_CE_Discovery in order to find out context information of registered CEs belong to the CM. After getting context information from registered CEs, the CM accesses TVWS DB to get the list of allowed channels such as the available channel and the restricted channel that can be used by TVBD networks or devices. To do that, the CM might send FCC identifier of each TVBD as required by FCC regulation. In case, TVWS DB is not available within a certain time limit, the CM requests each registered CE to send disconnection request to the CM.

After getting available or restricted channel lists from TVWS DB, the CM executes the procedure CM_Neighbor_CM_Discovery to get context information of neighbor CMs from the CDIS.

Once neighbor CM discovery is accomplished, the CM executes the procedure CM_Channel_Identification as depicted in figure 3. Through this procedure, the CM shall identify the available channel, the restricted channel, the operating channel already taken by the registered CE of the neighbor CM among allowed channels from TVWS DB.

The CM finally sets flag 'Initiate_Channel_Allocation' to be 1, in order to trigger the procedure CM_Channel_Allocation.

The procedure CM_Channel_Allocation is triggered if flag 'Initiate_Channel_Allocation' is set to be 1. This flag is set to be 1 if the following occurs:

- If the CM has done the procedure CM_Channel_Classification
- If the neighbor CM discovery has been updated
- If the registered CE discovery has been updated
- If the registered CE requests channel move and there are no available channels or restricted channels to allocate

As shown in figure 4, the CM firstly checks if Timer $T_{Refresh_TVWS_DB}$ is expired. If it is expired, the CM executes the procedure CM_TVWS_Channel_Update. If not, the CM enters the channel allocation process and checks current channel classification.

Based on current channel classification, the CM shall decide if individual channel assignment is possible for all registered CEs considering its neighbor CM. If possible, i.e., in individual channel assignment mode, the CM allocates an exclusive operating channel to each registered CE and sends reconfiguration request to registered CEs. If a registered CE does not accept the CM's reconfiguration request, the CM discards that registered CEs. The CM updates channel classification again to reflect channel allocation, and sets flag 'Initiate_Registered_CM_Channel_ Classification_Discovery' to be 1, Finally the CM sends context Information to CDIS.

If individual channel assignment mode is not possible, the CM enters co-channel sharing mode and shall apply a proper operating channel selection algorithm and a co-channel sharing mechanism to each registered CE. Negotiation might be needed if a negotiation with its neighbor CM is needed. An operating channel selection algorithm for the CM is shown in figure 5.

The procedure CM_TVWS_Channel_Update is periodically executed during the CM operation. If TVWS DB is updated, the CM executes the procedure CM_Initiate_Channel_Reallocation notifying channel shutdown to all registered CEs, and goes back to the procedure CM_Channel_Classification. In case, TVWS DB is not available within a certain time limit, the CM notifies shutdown of all operating channels to all registered CEs, and requests each registered CE to send disconnection request to the CM.

The procedure CM_Registered_CE_Discovery_Update is triggered if registered CE list of the CM has been changed. Through this procedure the CM executes the procedure CM_Registered_CE_Discovery and the procedure CM_Channel_Allocation one by one.

The procedure CM_Neighbor_CM_Discovery_Update is triggered if neighbor CM list has been changed. The CM executes the procedure CM_Neighbor_CM_Discovery and the procedure CM_Channel_ Allocation by turns.

The procedure CM_Initiate_Registered_CE_Channel_Move is triggered if a registered CE of the CM requests channel move due to failure of required quality of service (QoS) with allocated operating channel from the CM. As depicted in figure 6 the CM shall allocate a new operating channel to the CE requesting channel move if there are available channels or restricted channels. After that the CM shall update channel classification, and send context information to the CDIS. If there are no available channels or restricted channels to allocate, the CM shall set flag 'Initiate_Channel_Allocation' to be 1 and execute the procedure CM_Channel_Allocation.

The procedure CM_Inform_Event is triggered if the CM detected an event that should inform to the CDIS or its neighbor CMs. The specific procedure and message with contents are presented in Section 6.2.9 for procedure and Section 6.3.8.5, Section 6.3.8.6, Section 6.3.8.7, and 6.3.8.8 for message, respectively.

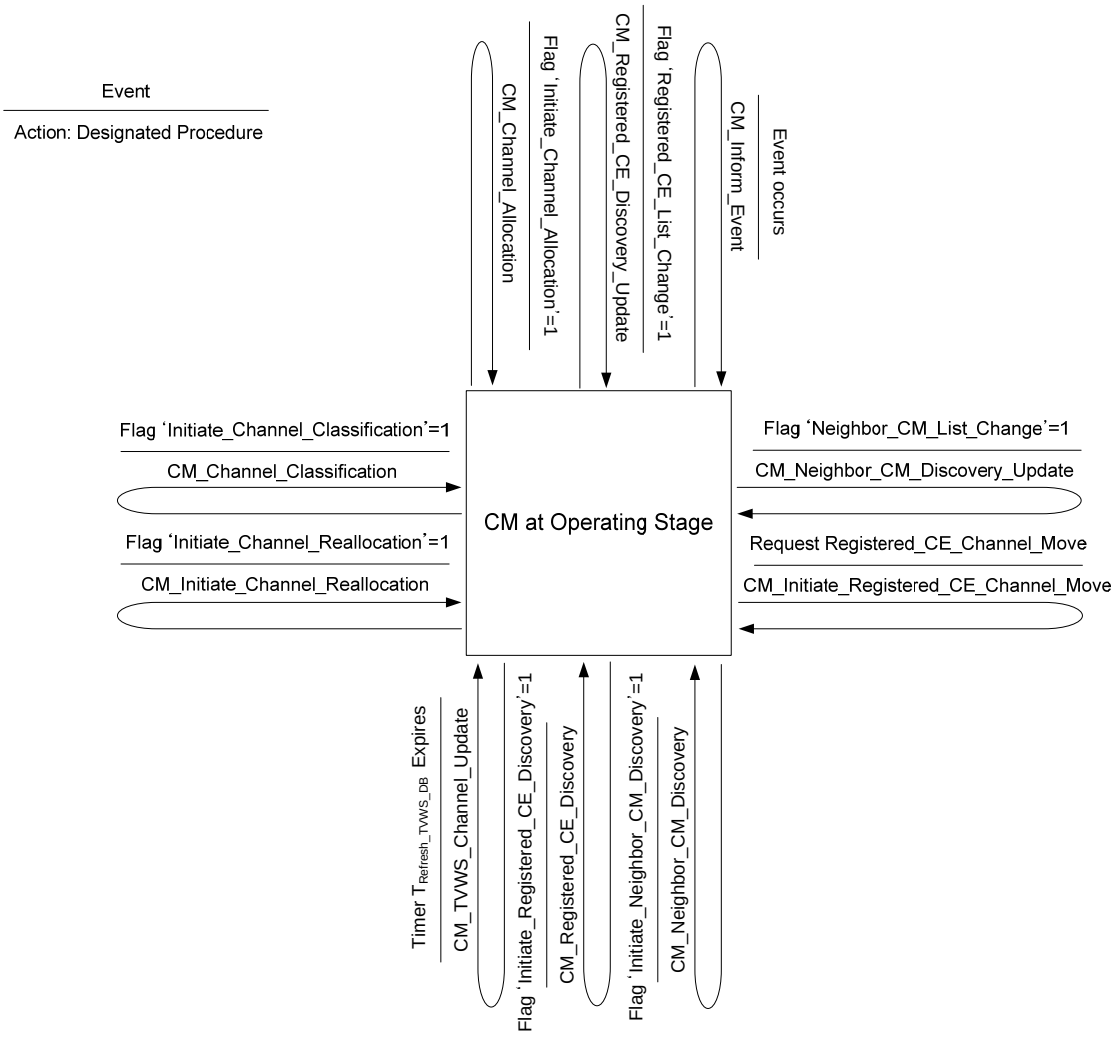


**Figure 4 CM operating procedures**

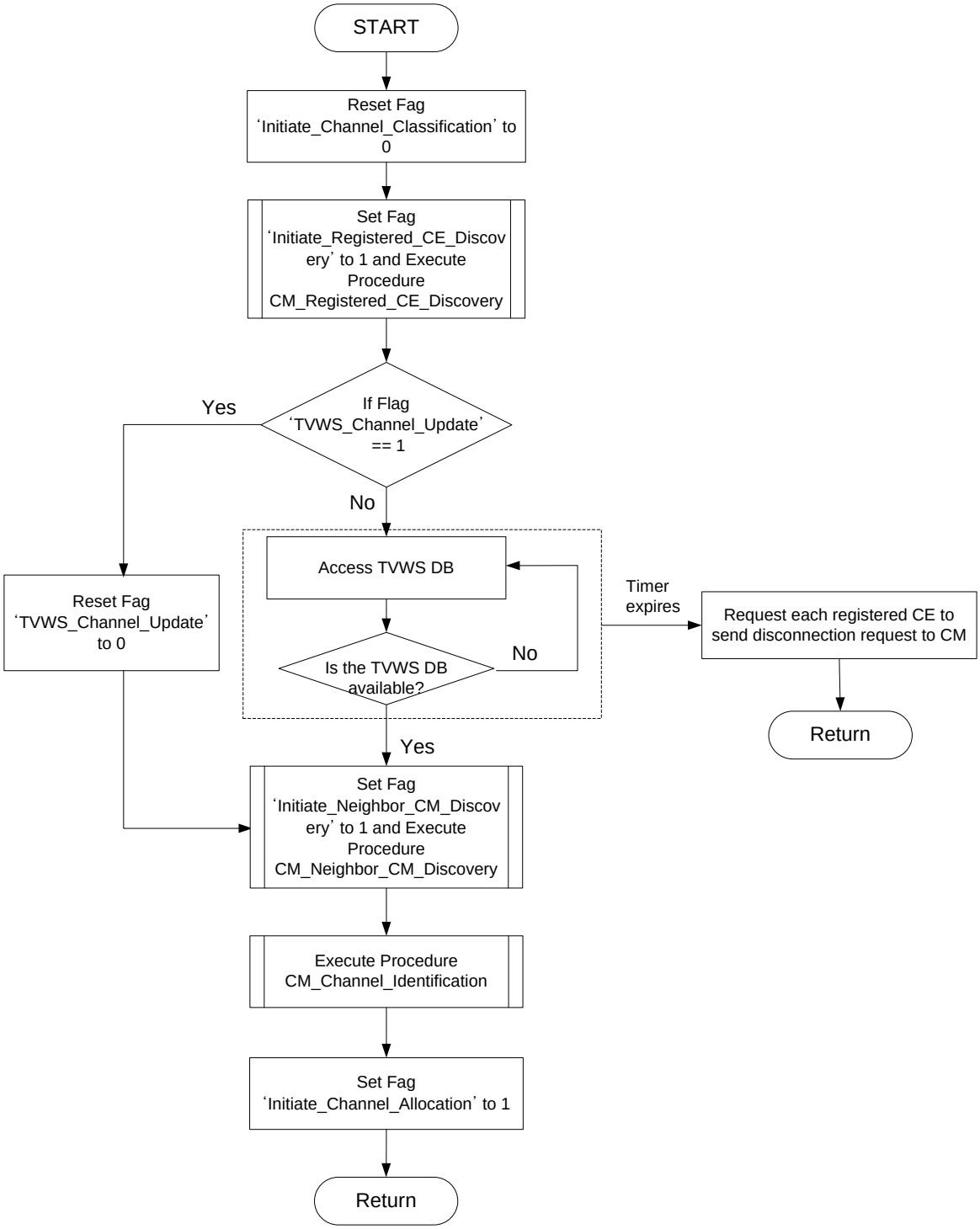


**Figure 5 Procedure CM_Channel_Classification**

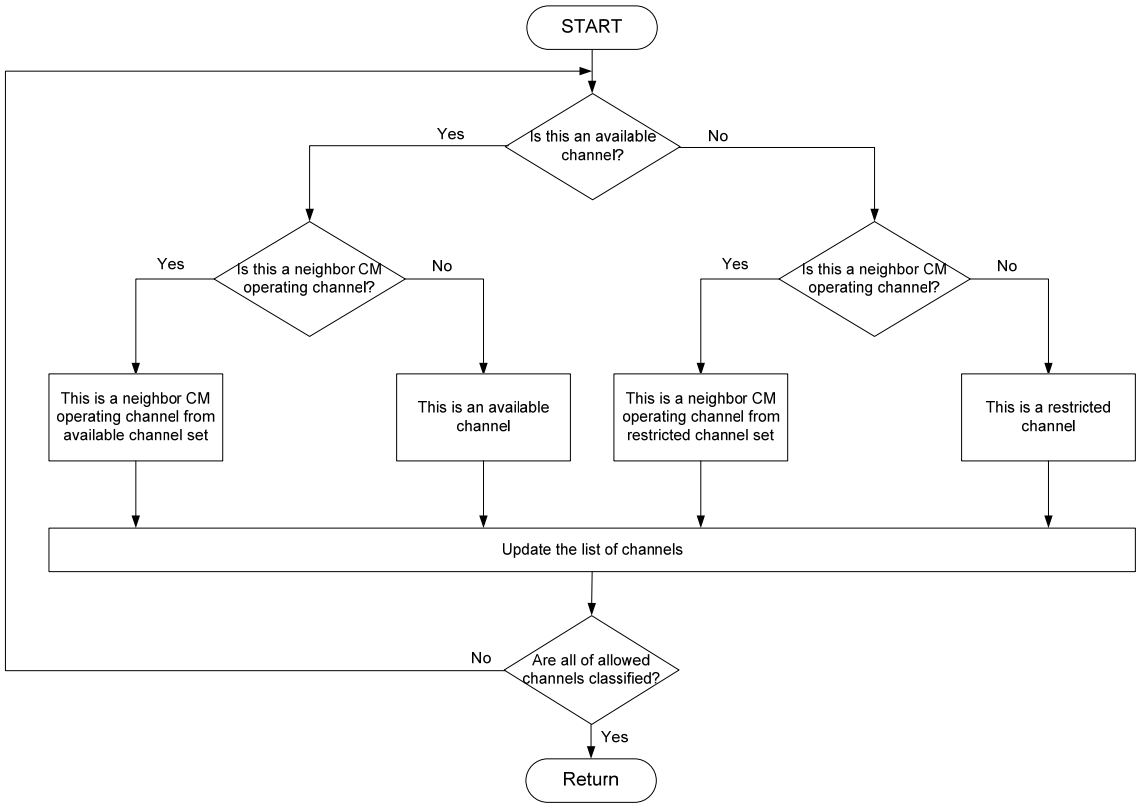


**Figure 6 Procedure CM_Channel_Identification**

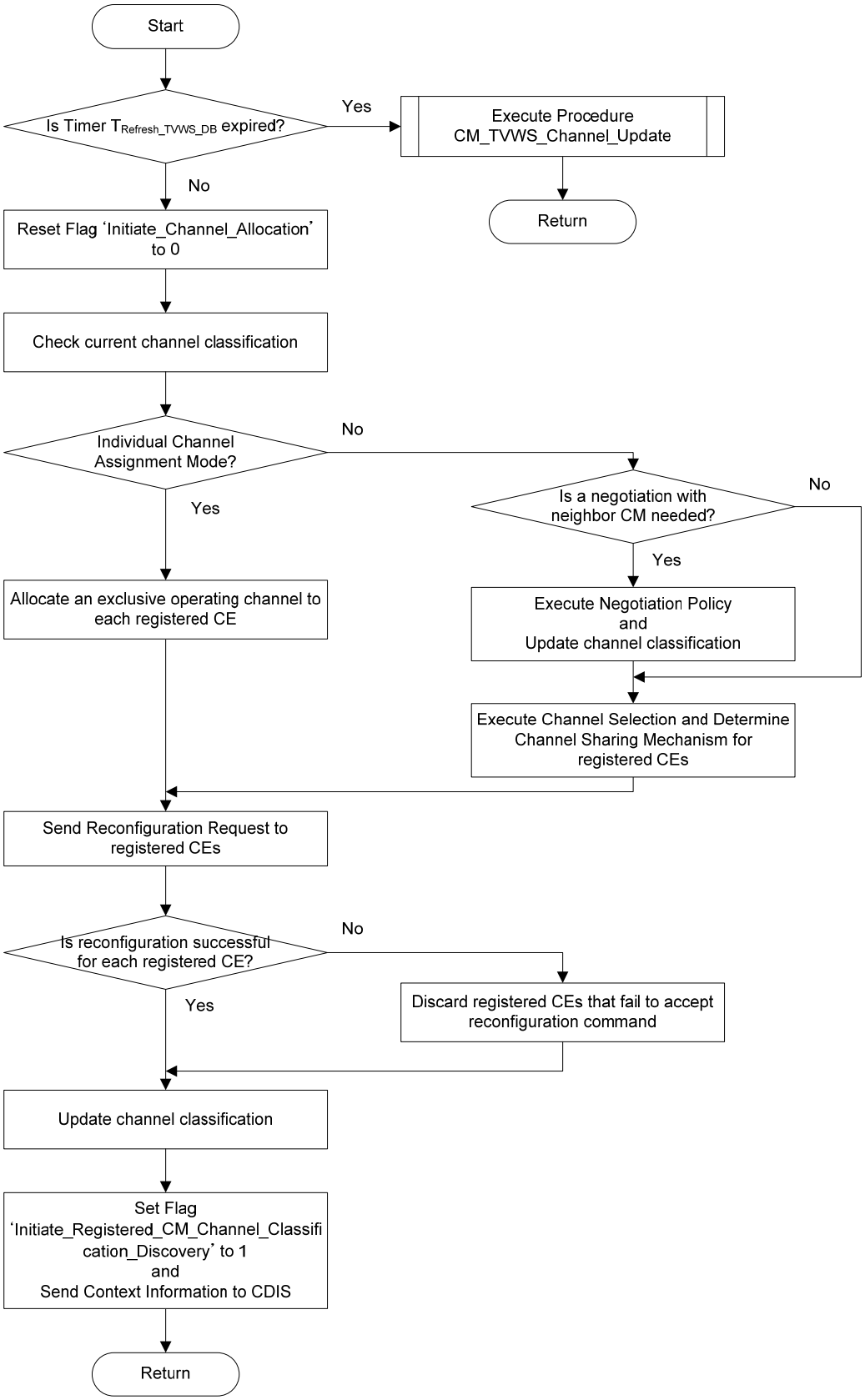


**Figure 7 Procedure CM_Channel_Allocation**

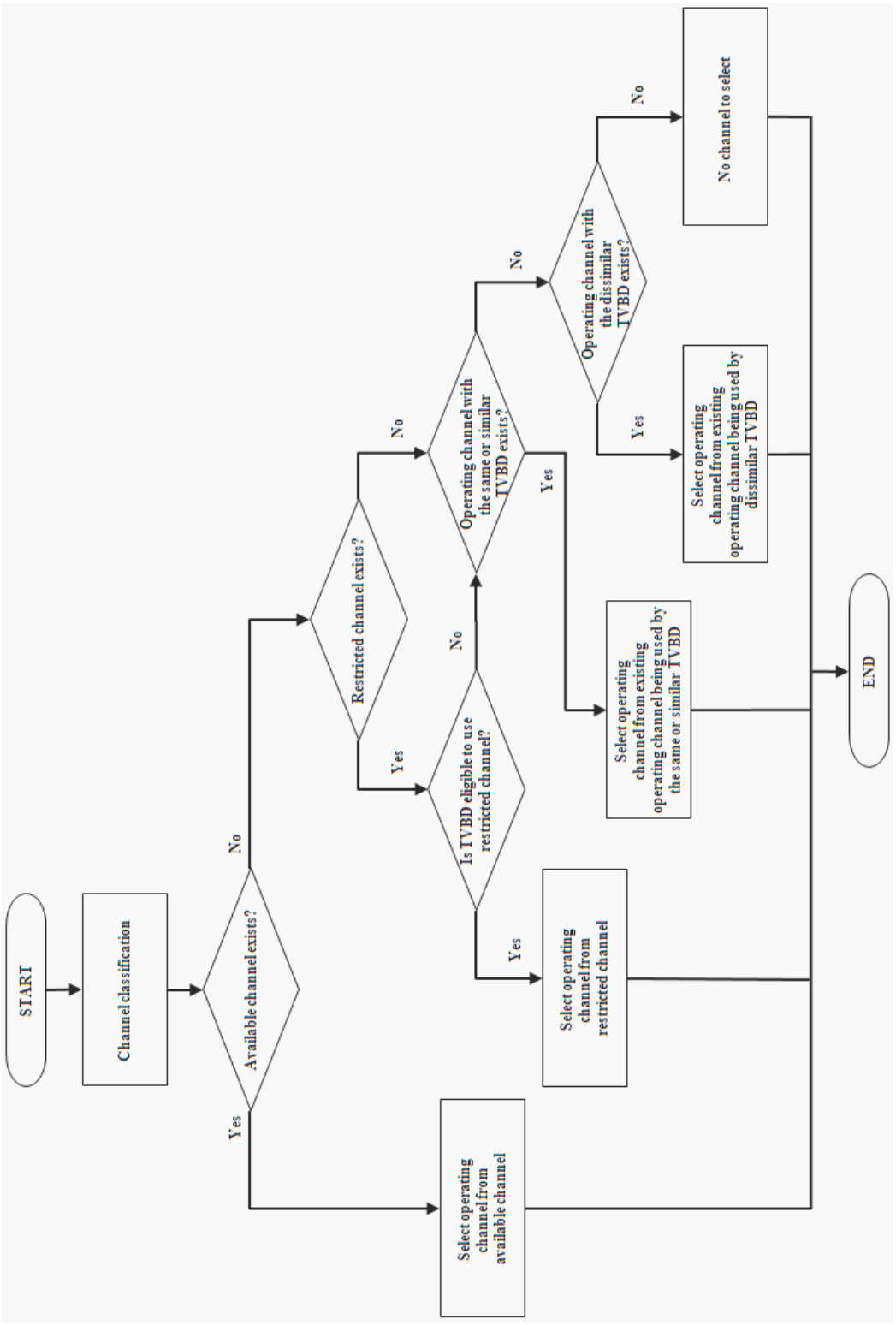


**Figure 8 Operating channel selection algorithm**

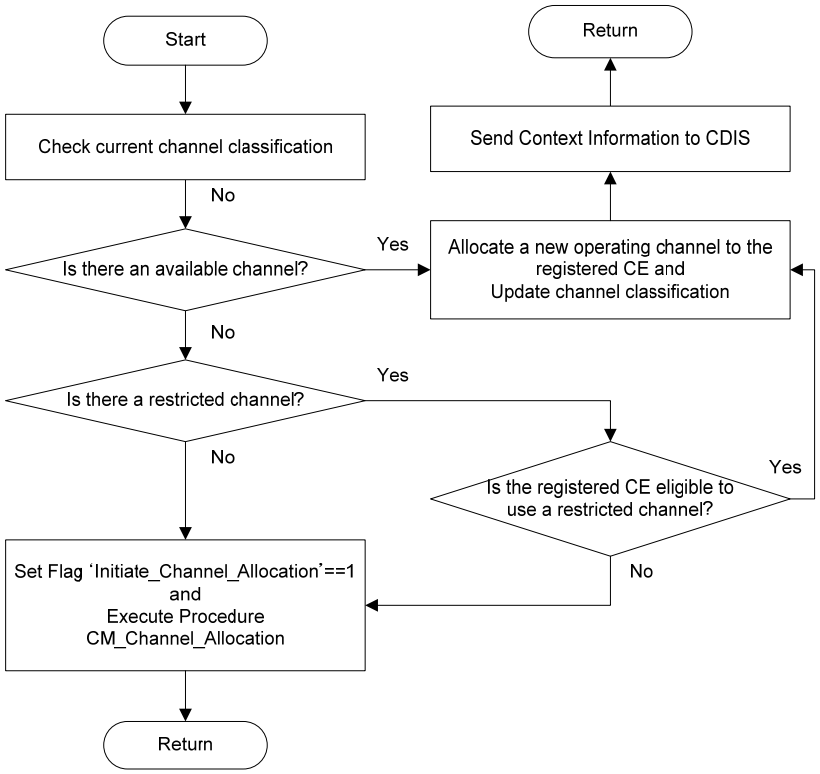


**Figure 9 Procedure CM_Initiate_Registered_CE_Channel_Move**

### 7.2.2 CE operation

Figure 7 describes coexistence enabler operating procedures that define a specific event and designated procedure triggered by it. Operating procedures of coexistence manager are as follows:

- CE_Inform_Context_Information
- CE_Request_Channel_Move
- CE_Inform_Event
- CE_TVBD_Reconfiguration

The procedure CE_Inform_Context_Information is triggered if the CE receives context information request from the CM. The main purpose of this procedure is to provide the fundamental information of the corresponding TVBD to the CM. When this procedure is triggered, the CE sends the fundamental information to the CM. The considered fundamental information of the TVBD is TVBD type, TVBD network type and TVBD geolocation, etc. The specific procedure and message with contents are presented in Section 6.2.3 for procedure and Section 6.3.2.3 and 6.3.2.4 for message, respectively.

The procedure CE_Request_Channel_Move is triggered if the CE detects failure of required quality of service (QoS) with allocated operating channel from the CM. The main purpose of this procedure is to request a new operating channel of the CE to the CM. This procedure is implemented by notifying the TVBD QoS change event of the corresponding CE to the CM where the TVBD QoS change event is triggered when QoS of the corresponding TVBD is degraded under the required reliability. Through this procedure, the CE shall request a new operating channel to the CM. The specific procedure and message

with contents are presented in Section 6.2.9 for procedure and Section 6.3.8.1 and 6.3.8.2 for message, respectively.

The procedure CE_Inform_Event is triggered if the CE event is occurred. This procedure is used to notify the detected event of the corresponding CE to CM, which gives effect on the neighbor discovery. Then, when this procedure is triggered, the CE informs the detected events to the CM. As a reported CE, we consider TVBD QoS change, TVBD geolocation change and TVBD coverage change events. As mentioned above, through the TVBD QoS change event, the CE requests a new operating channel to the CM. Further, because of having effects on the neighbor discovery, TVBD geolocation and overage change events are considered as a reported CE event. The specific procedure and message with contents are presented in Section 6.2.9 for procedure and Section 6.3.8.1 and 6.3.8.2 for message, respectively.

The procedure CE_TVBD_Reconfiguration is triggered if the CE receives reconfiguration request from the CM. Through this procedure the CE shall reconfigure TVBD as the CM requested where the considered reconfiguration parameters are coexistence mode, channel classification list and service duration, etc. The CE shall check the validity of allocated operating channel from the CM by asking TVWS DB. After then, the CE gives the reconfiguration response which provides the status information whether the corresponding reconfiguration parameter from the CM is accepted or not. The specific procedure and message with contents are presented in Section 6.2.7 for procedure and Section 6.3.6.1 and 6.3.6.2 for message, respectively.

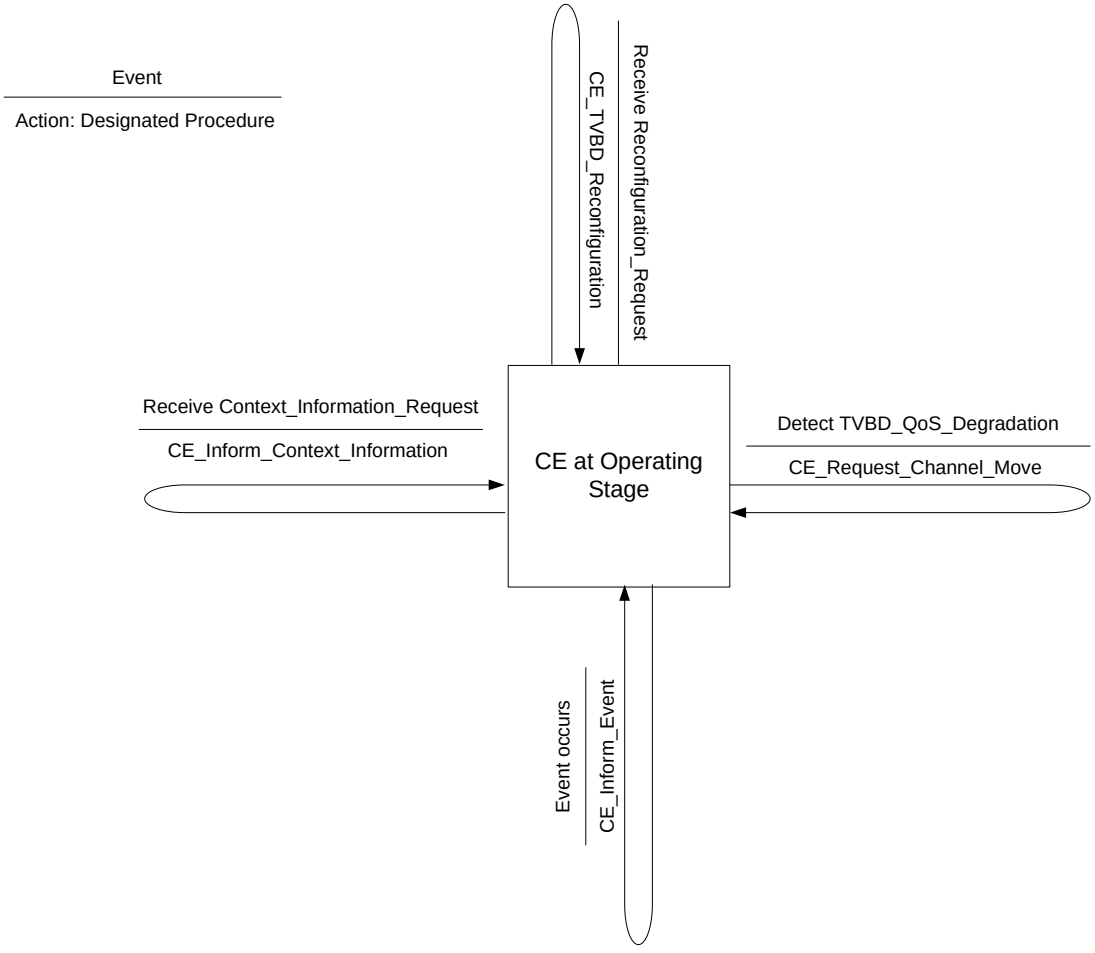


**Figure 10 CE operating procedures**

### 7.2.3 CDIS operation

Figure 8 describes coexistence enabler operating procedures that define a specific event and designated procedure triggered by it. Operating procedures of coexistence manager are as follows:

- CDIS_TVWS_Channel_Update
- CDIS_Neighbor_CM_Discovery
- CDIS_Registered_CM_Channel_Classification_Discovery
- CDIS_Inform_Event

The procedure CDIS_TVWS_Channel_Update is periodically executed during the CDIS operation whenever the refresh timer TRefresh_TVWS_DB is expired. The main purpose of this procedure is to update TVWS channel information of the CDIS from TVWS DB. Then, when this procedure is triggered, the CDIS accesses the TVWS DB and updates the TVWS channel information. The considered TVWS channel information is allowed TVWS channel list and channel use constraint. The specific procedure and message with contents are presented in Section 6.2.5 for procedure and Section 6.3.4.1 and 6.3.4.2 for message, respectively.

The procedure CDIS_Neighbor_CM_Discovery is triggered if flag 'Initiate_Neighbor_CM_Discovery' is set to be 1. This flag is set to be 1 if the registered CM list or context information of the registered CM has been updated. The main purpose of this procedure is to find inter-CM TVBD neighbor that might cause harmful co-channel interference between them. Then, this procedure is triggered, the CDIS updates the context information from all registered CMs. Using context information from all registered CMs, CDIS regards two or more TVBD as an inter-CM TVBD neighbor if they interfere each other with the same operating channel due to their geo-location, transmission range, interference range, etc. Based on this procedure, CDIS discovers the inter-CM TVBD neighbor and provides neighbor discovery information to the CMs where the considered neighbor discovery parameters are neighbor CM ID list, neighbor CE ID list and neighbor CE channel number list. The specific procedure and message with contents are presented in Section 6.2.4 for procedure and Section 6.3.3.1 and 6.3.3.2 for message, respectively.

The procedure CDIS_Registered_CM_Channel_Classification_Discovery is triggered if flag 'Initiate_CDIS_ Registered_CM_Channel_Classification_Discovery' is set to be 1. This flag is set to be 1 if channel classification of the registered CM has been updated. The main purpose of this procedure is to update the channel classification information of each registered CM. Then, when this procedure is triggered, the CDIS shall gather information on channel classification of each registered CM. The specific procedure and message with contents are presented in Section 6.2.5 for procedure and Section 6.3.4.5 and 6.3.4.6 for message, respectively.

The procedure CDIS_Inform_Event is triggered if the CDIS event is occurred. This procedure is used to notify the detected event of the corresponding CDIS to the CM, which gives effect on the resource allocation of the CM. Then, when this procedure is triggered, the CDIS informs the detected events to the CM. As a reported CDIS event, we consider TVWS channel information change, neighbor CMs information change and neighbor CEs information change events. Through the TVWS channel information change event, the CDIS informs the TVWS channel information update to the CM. Further, to check the neighbor discovery update, neighbor CMs and CEs information change events are considered. The specific procedure and message with contents are presented in Section 6.2.9 for procedure and Section 6.3.8.3 and 6.3.8.4 for message, respectively.

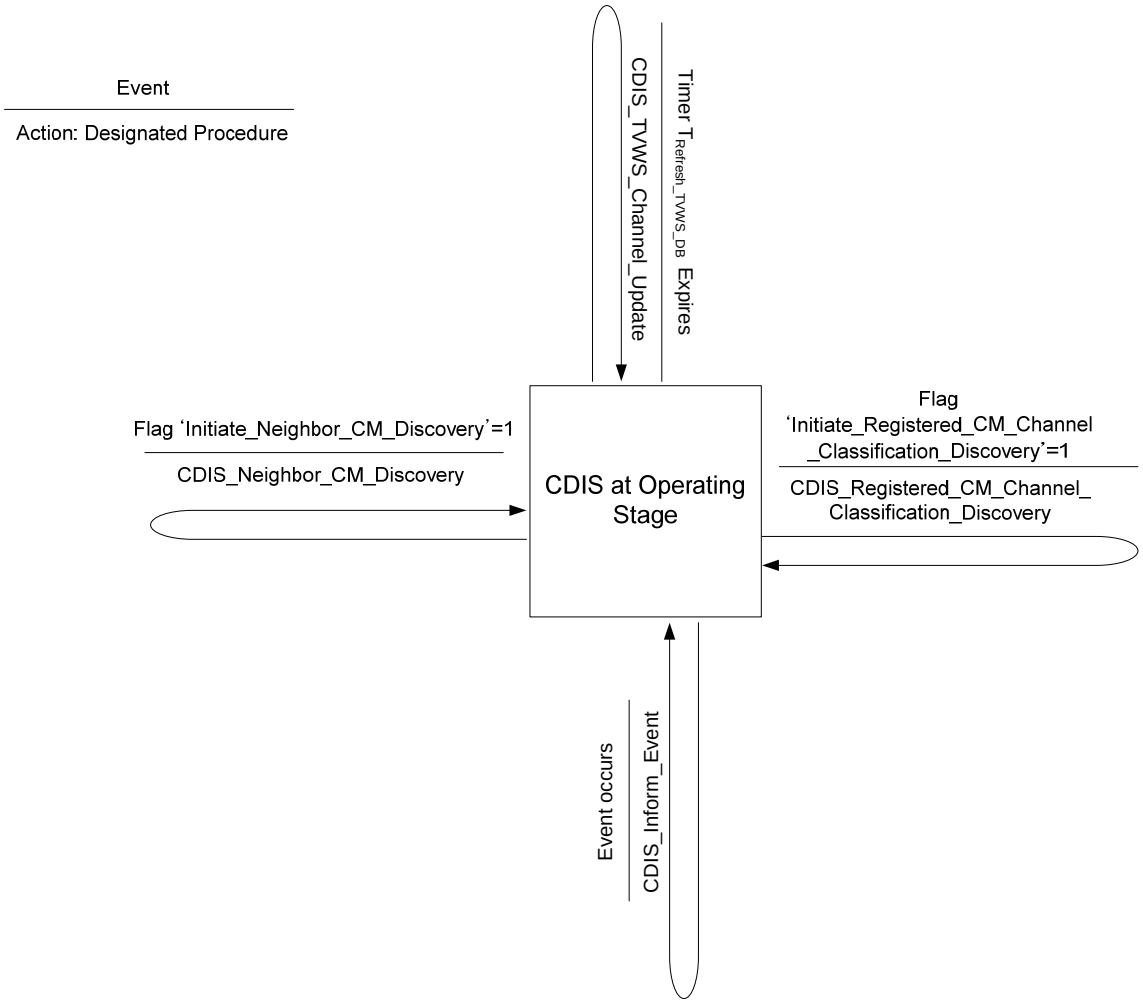


**Figure 11 CDIS operating procedures**

## 7.3 Co-channel sharing mechanism and algorithm

### 7.3.1 CE operation

CE operation is described below using SDL flowcharts.

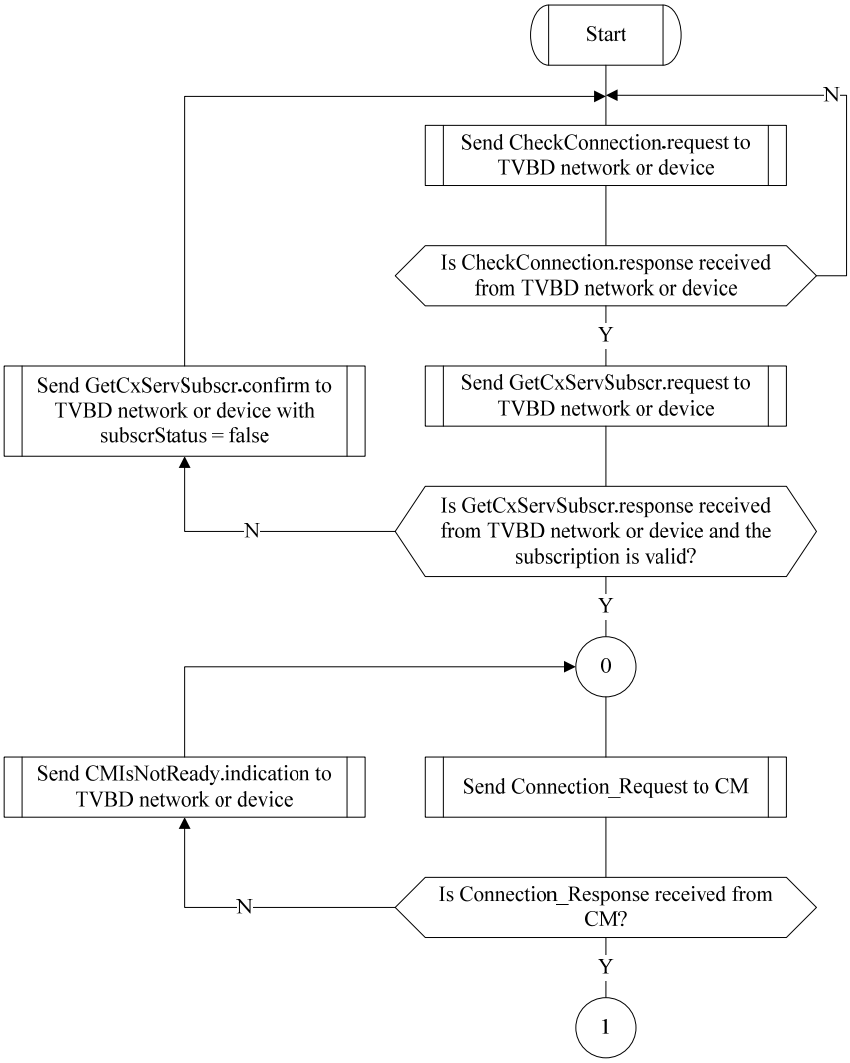


**Figure 12 CE operation**

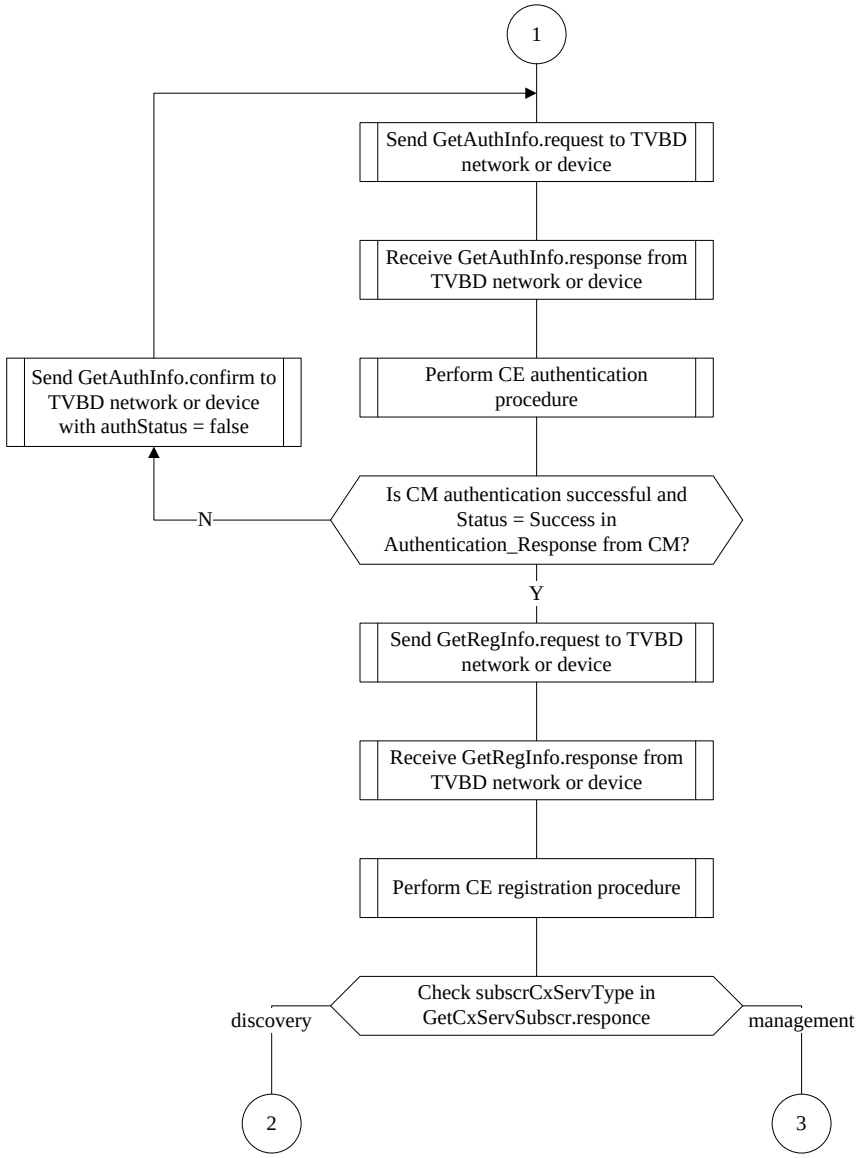


**Figure 13 CE operation**

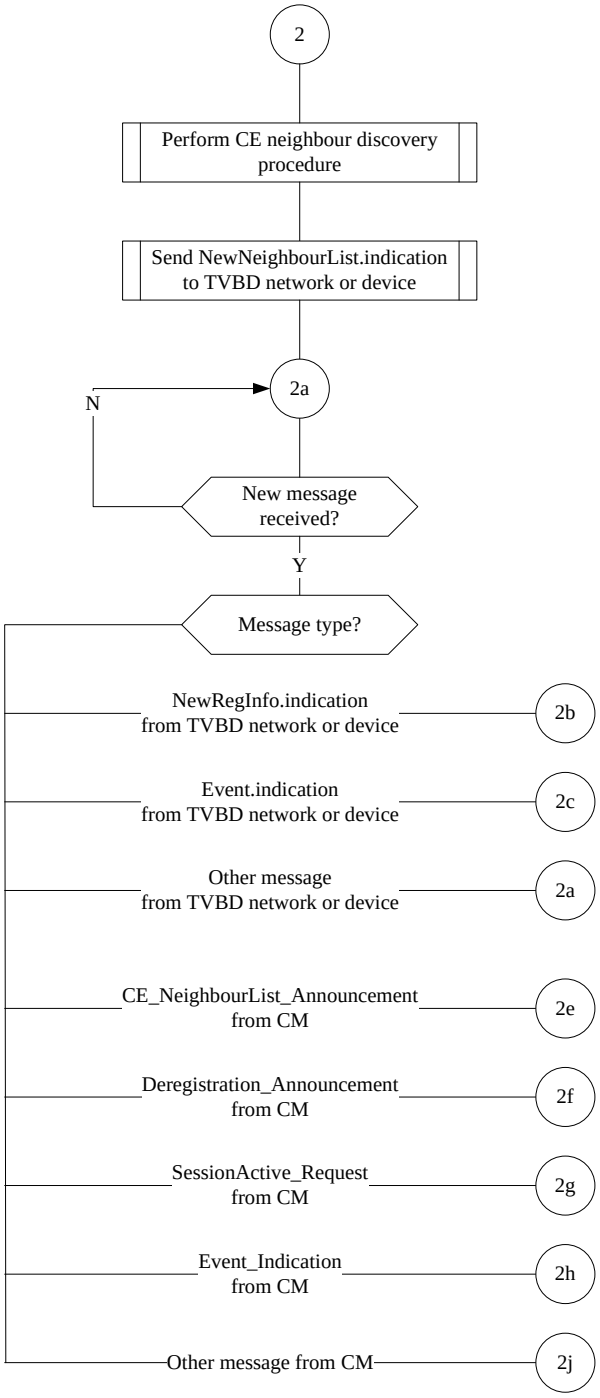


**Figure 14 CE operation**

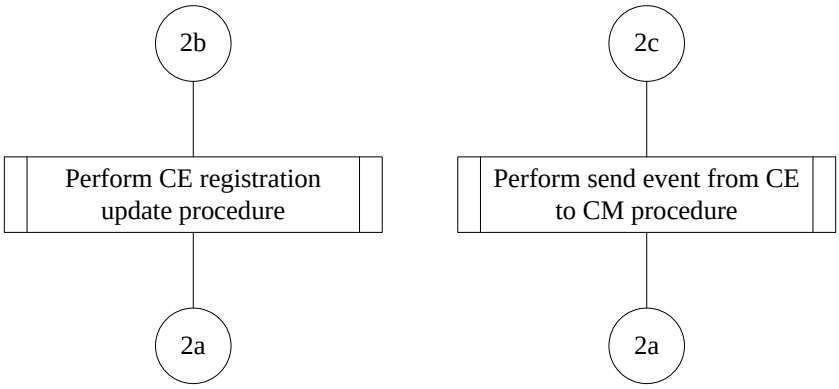


**Figure 15 CE operation**

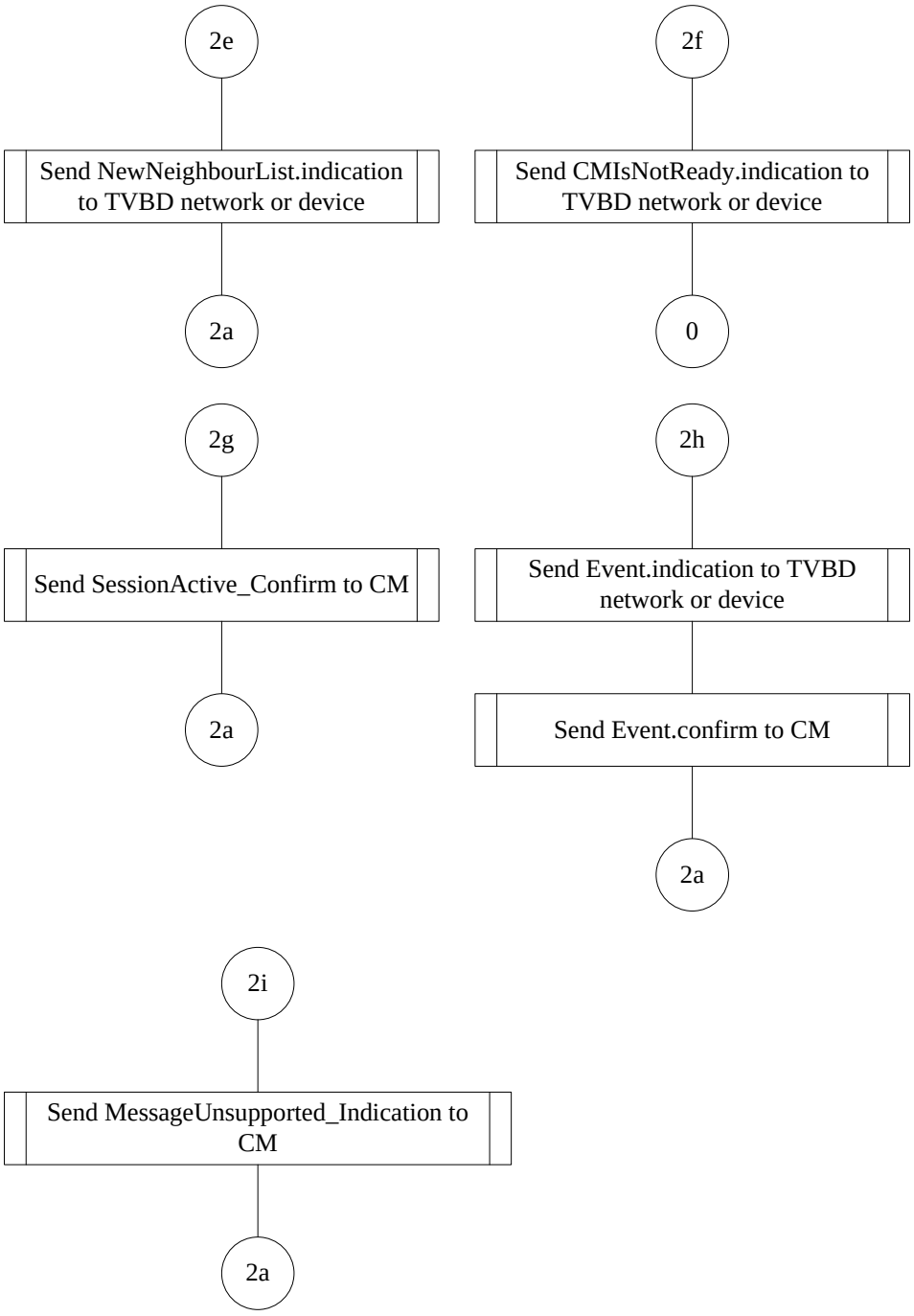


**Figure 16 CE operation**

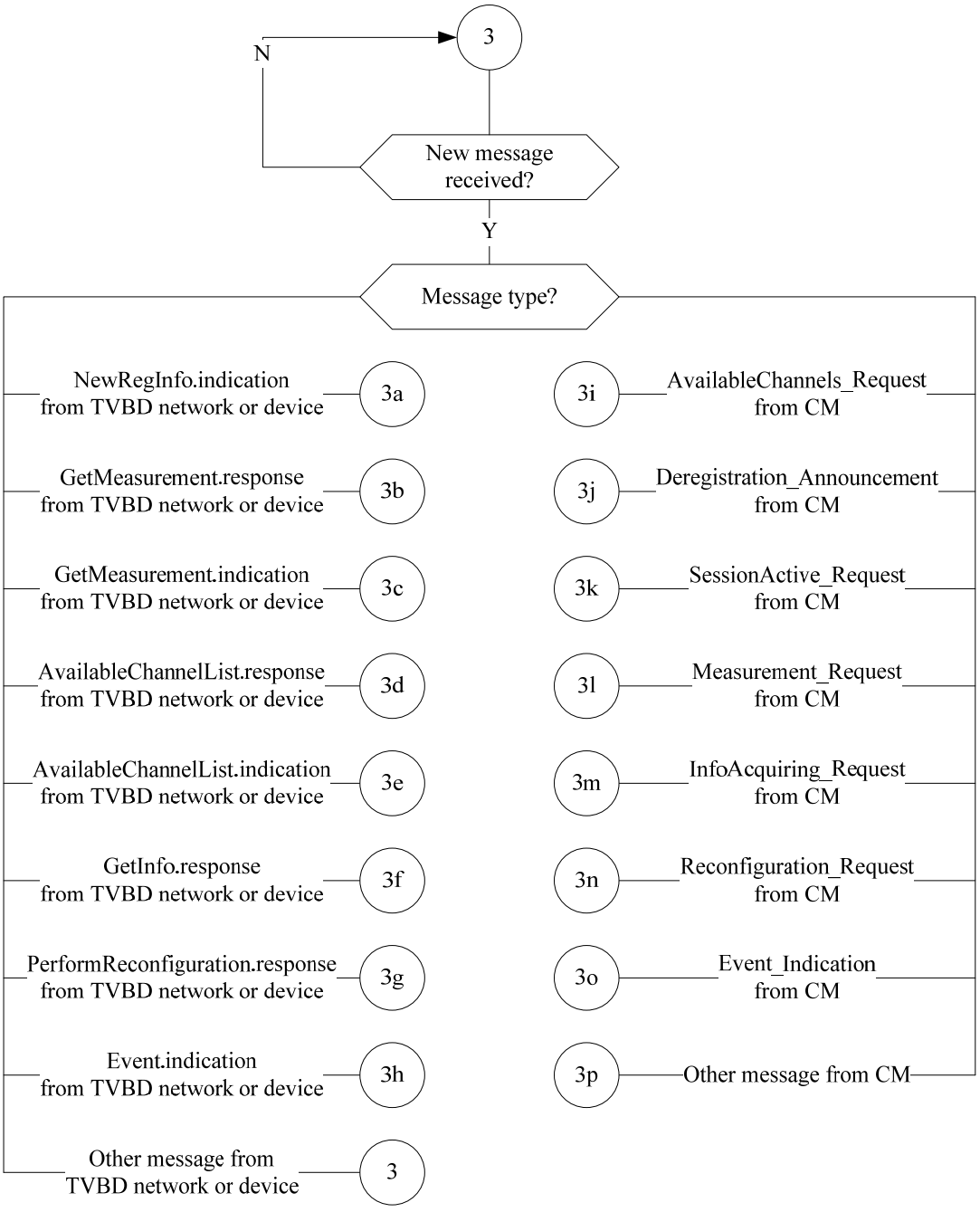


**Figure 17 CE operation**

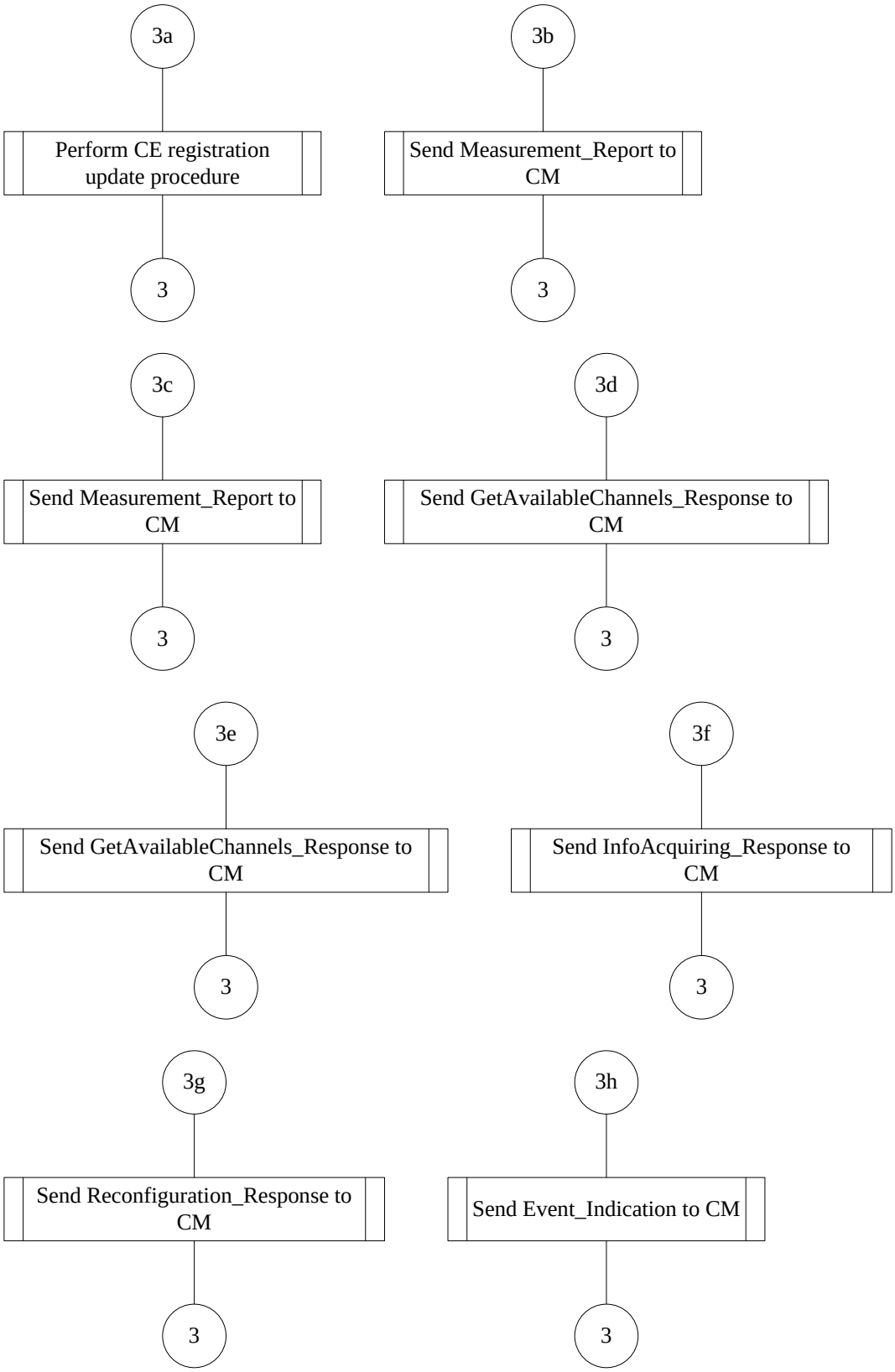


**Figure 18 CE operation**

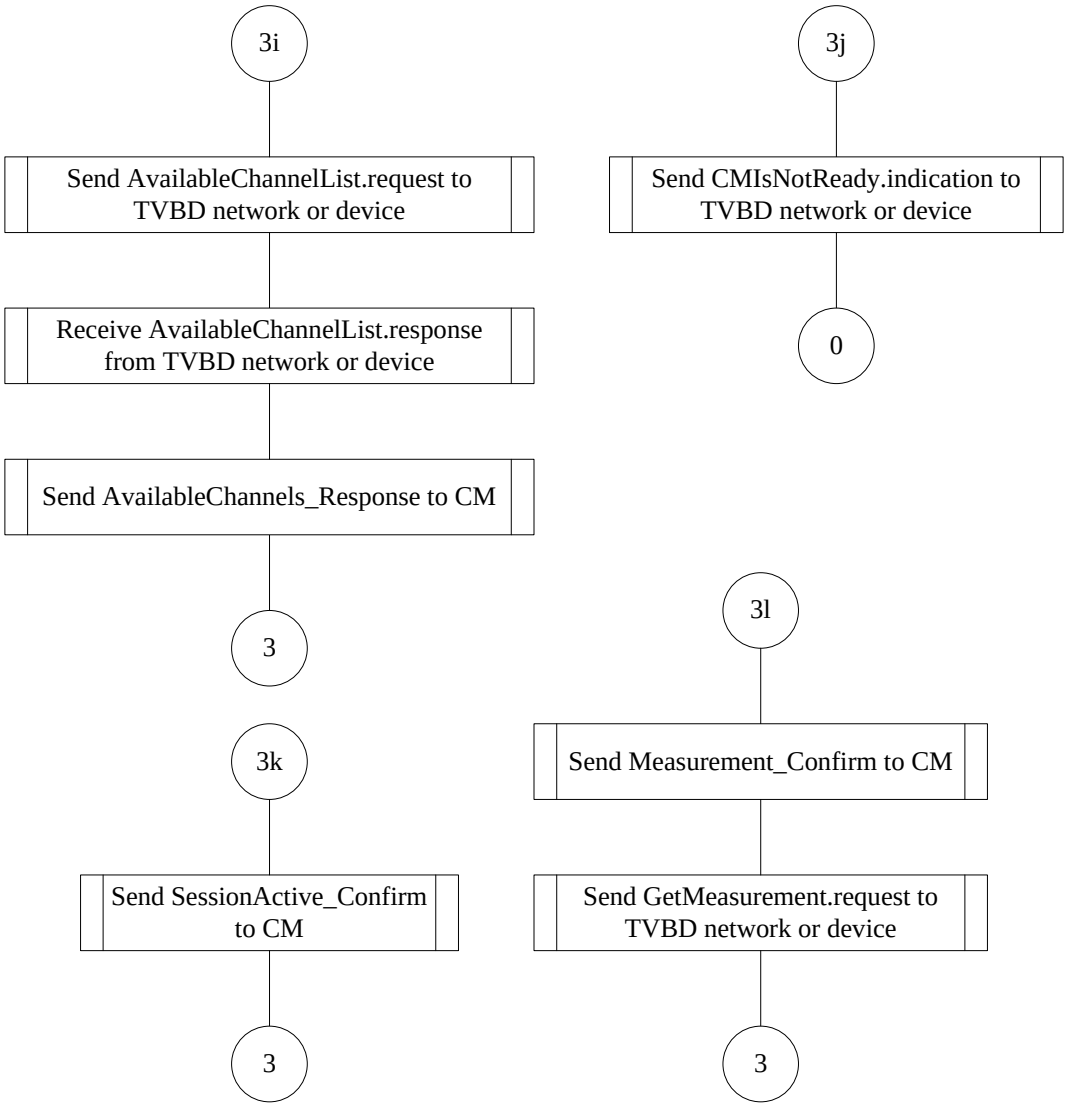


**Figure 19 CE operation**

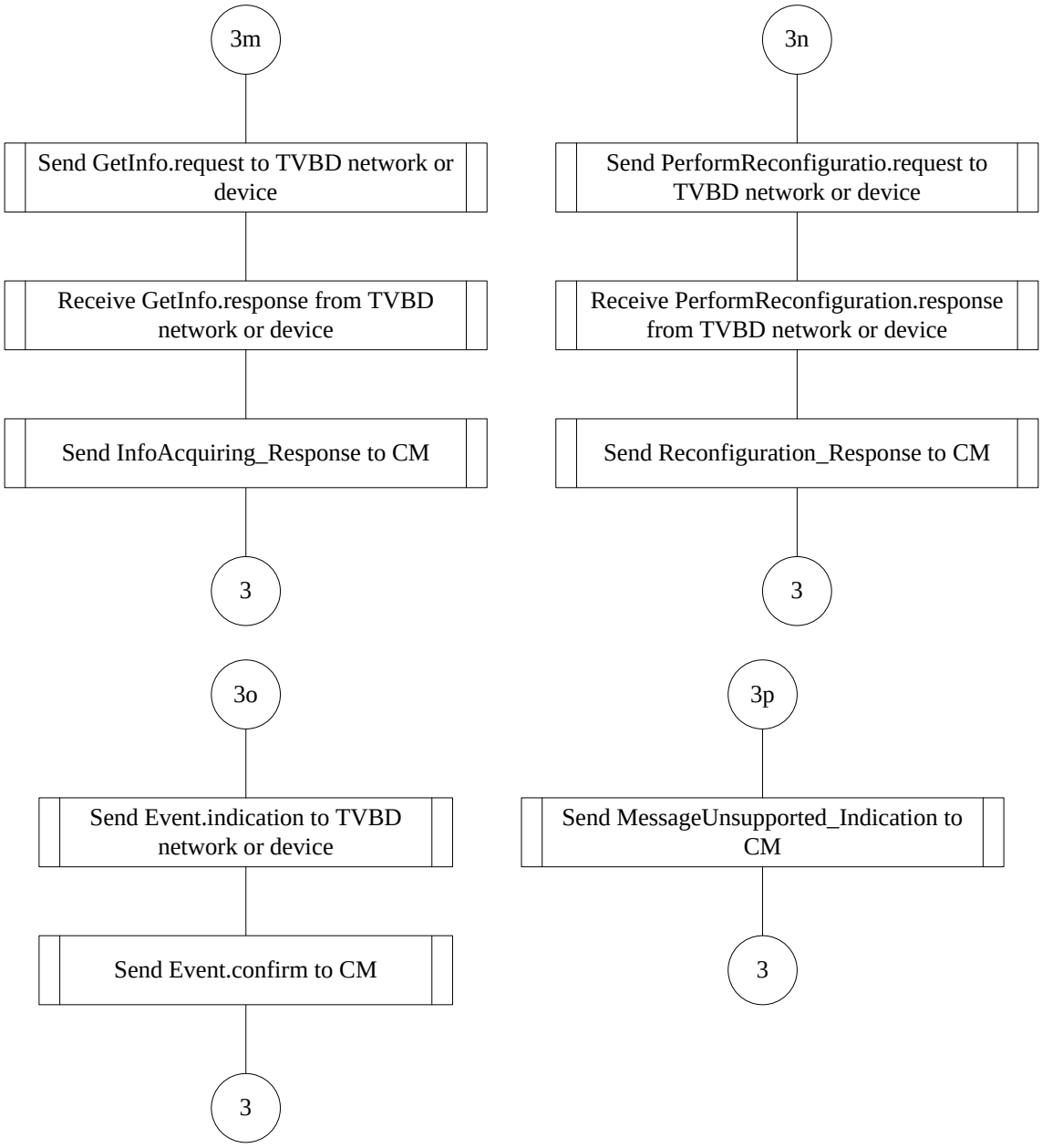


**Figure 20 CE operation**

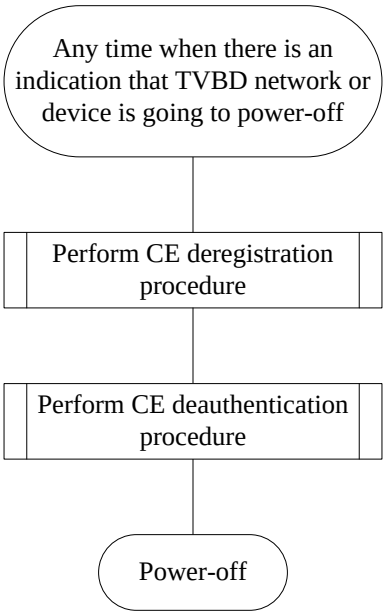


**Figure 21 CE operation**

### 7.3.2 CM operation

CM operation is described below using SDL flowcharts.

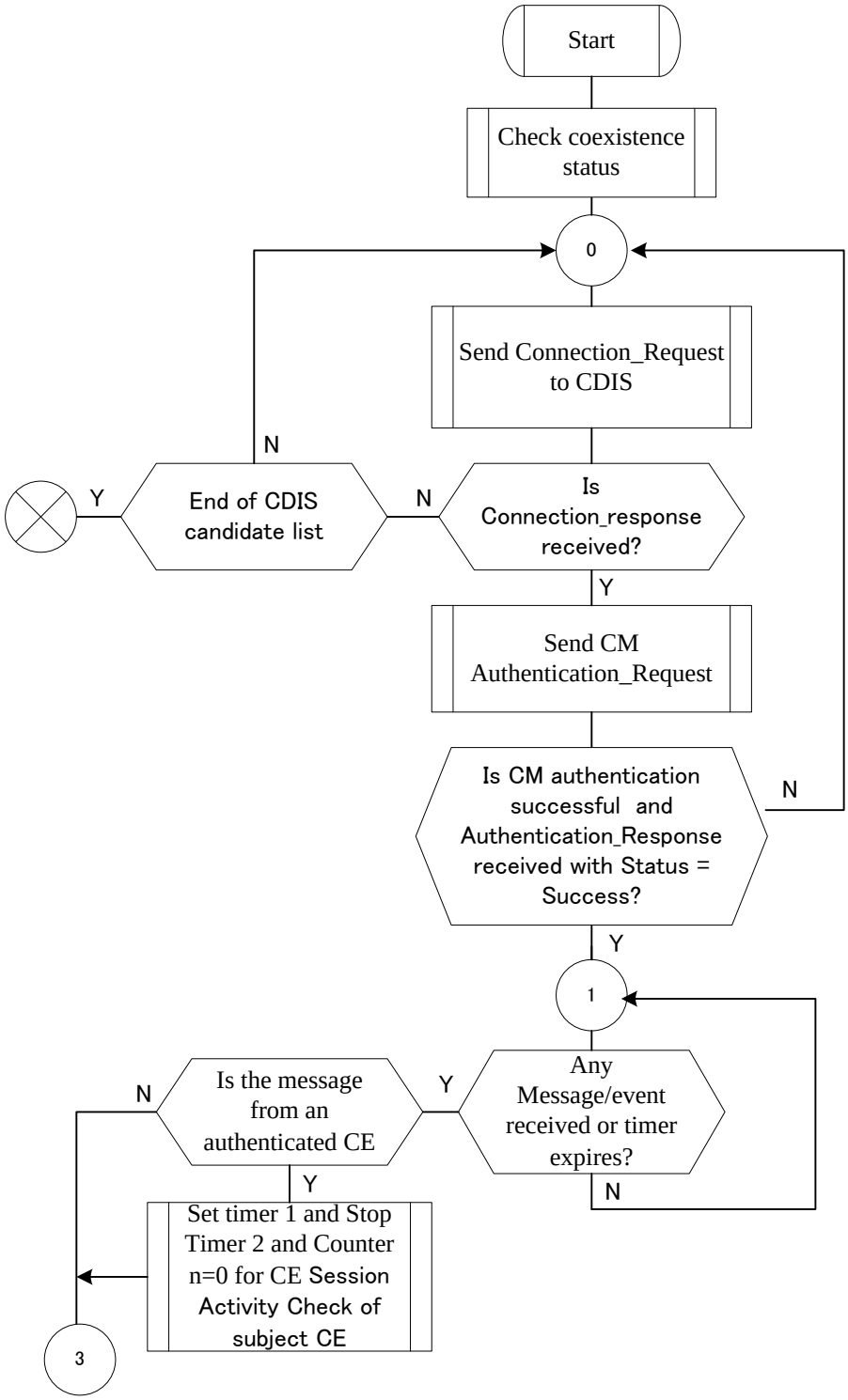


**Figure 22 CM operation**

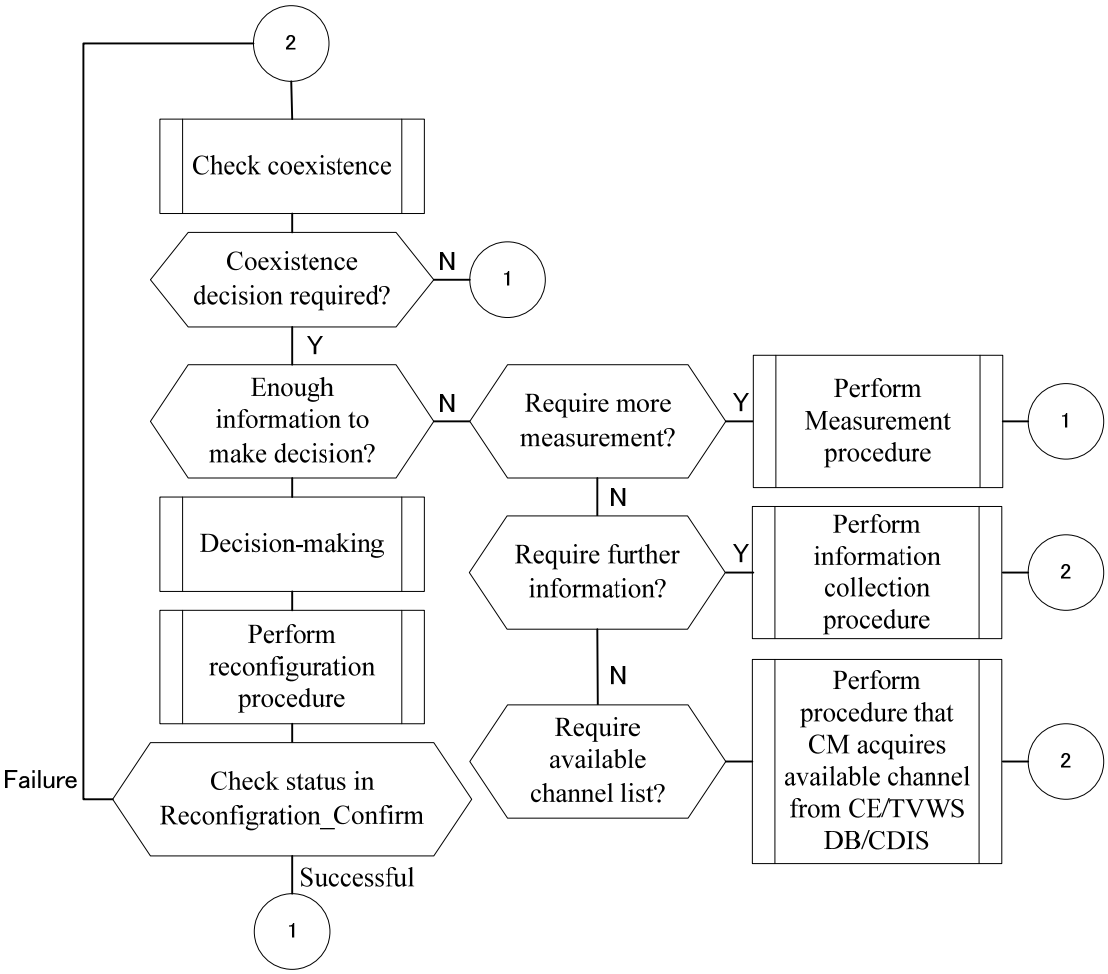


**Figure 23 CM operation**

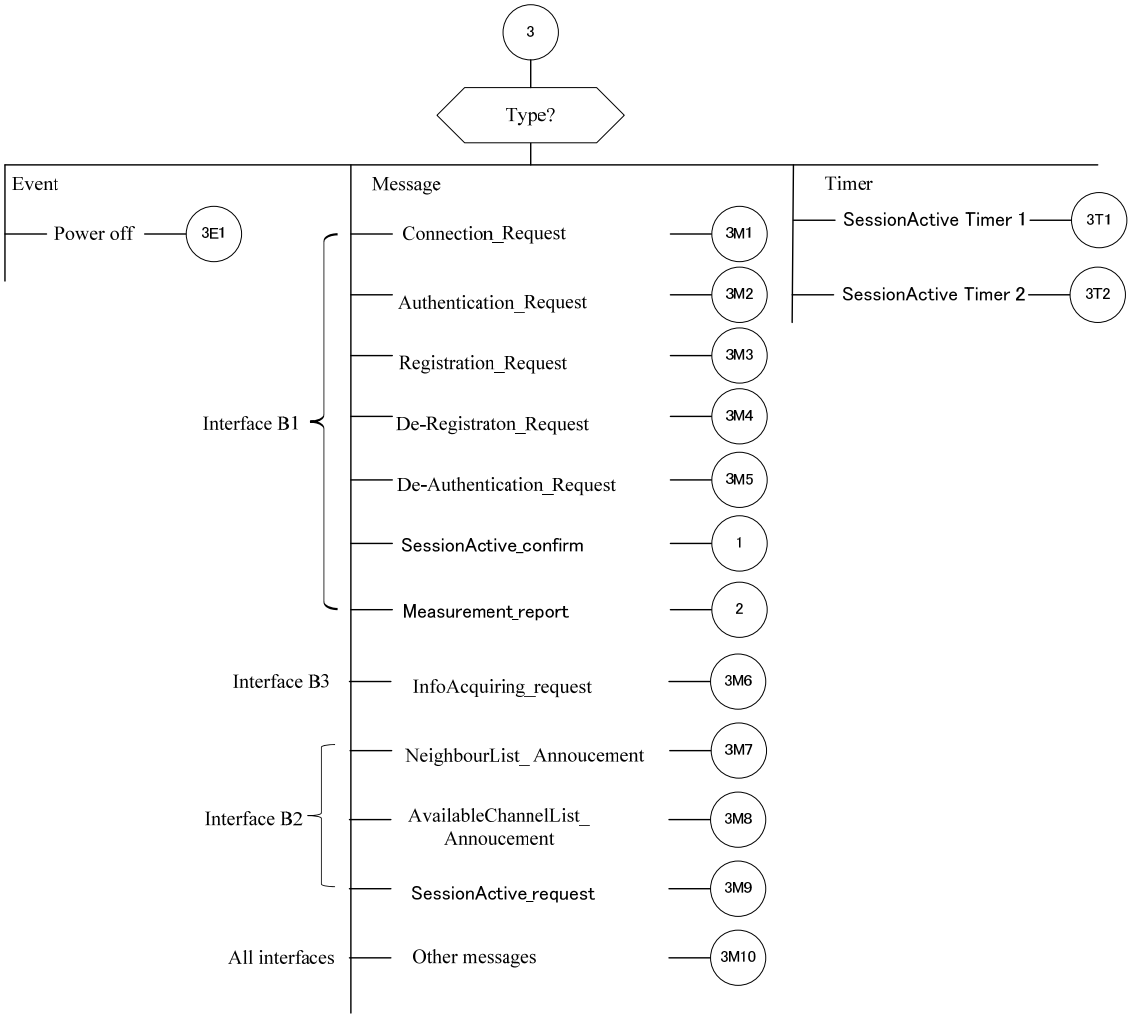


**Figure 24 CM operation**

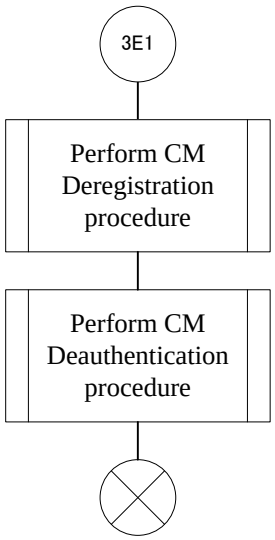


**Figure 25 CM operation**

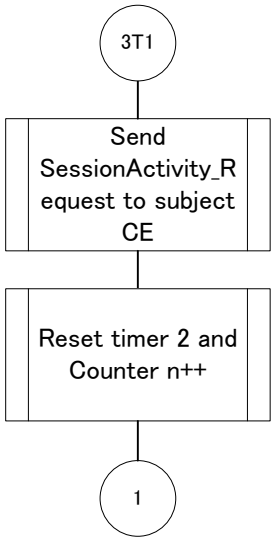


**Figure 26 CM operation**

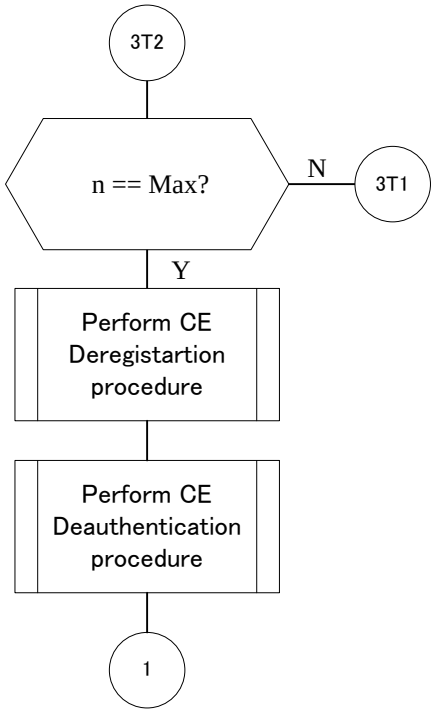


**Figure 27 CM operation**

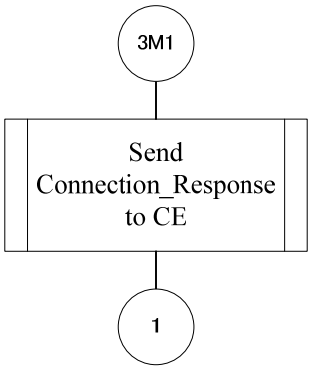


**Figure 28 CM operation**

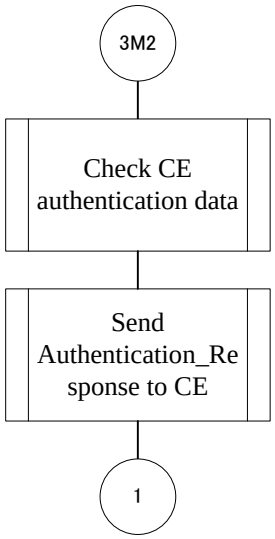


**Figure 29 CM operation**

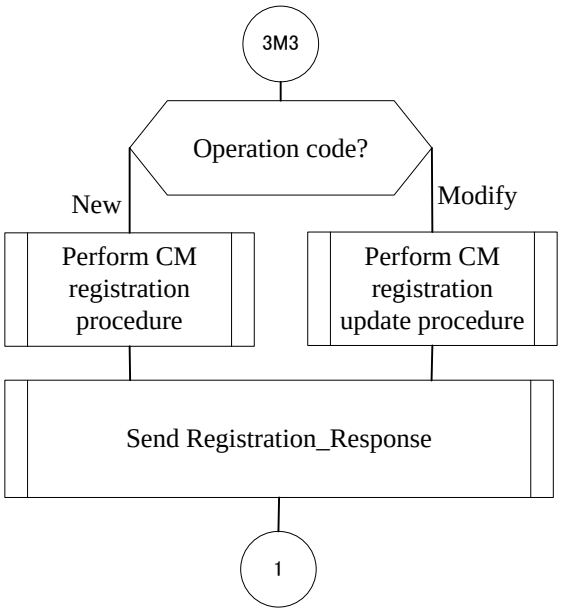

**Figure 30 CM operation**

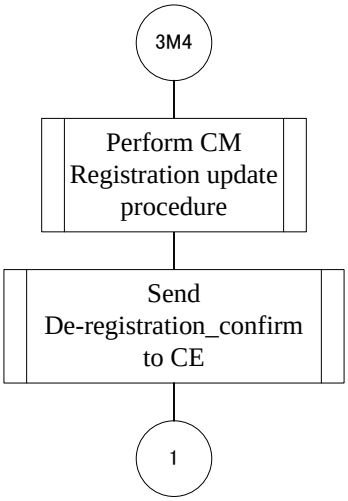


**Figure 31 CM operation**

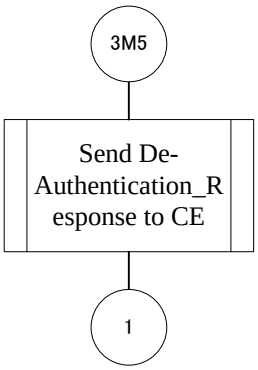


**Figure 32 CM operation**

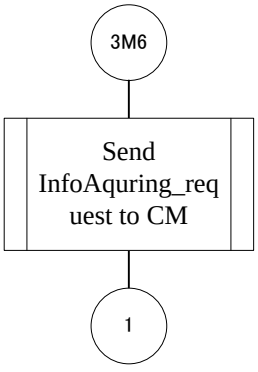


**Figure 33 CM operation**

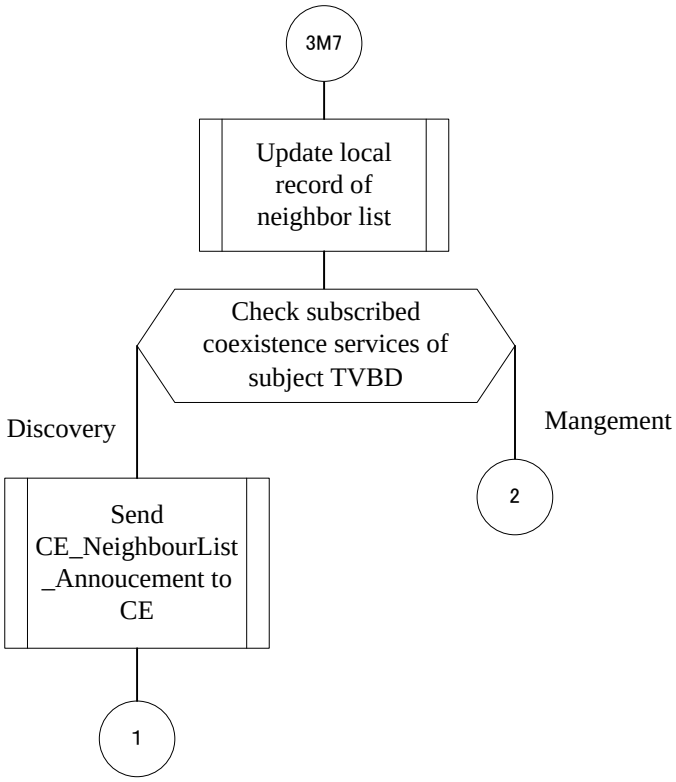


**Figure 34 CM operation**

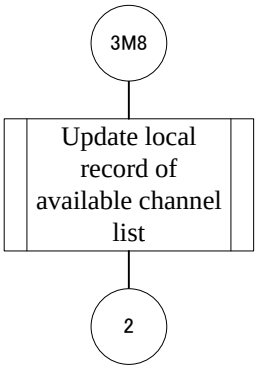


**Figure 35 CM operation**

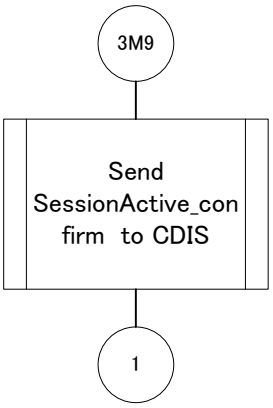


**Figure 36 CM operation**

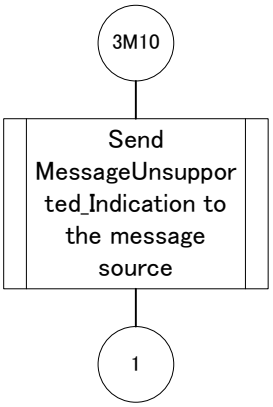


**Figure 37 CM operation**

### 7.3.3 CDIS operation

CDIS operation is described below using SDL flowcharts.

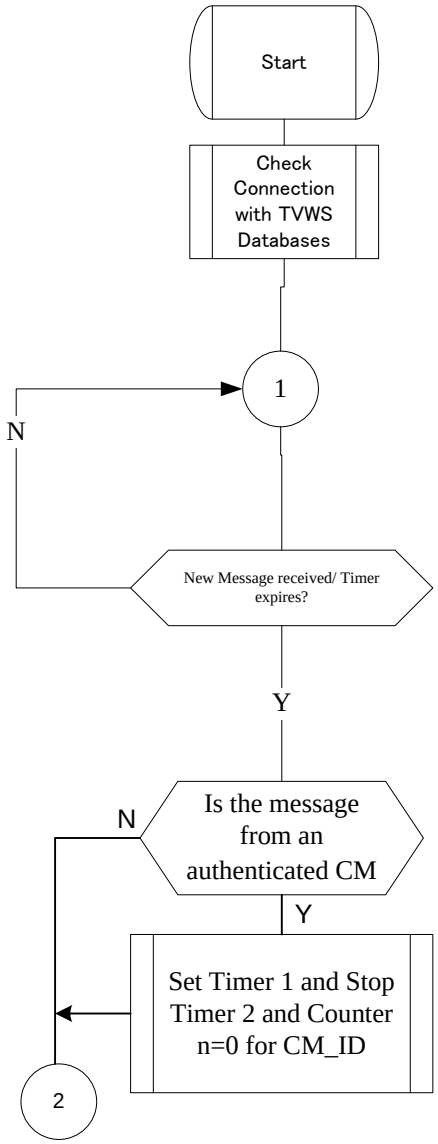


**Figure 38 CDIS operation**

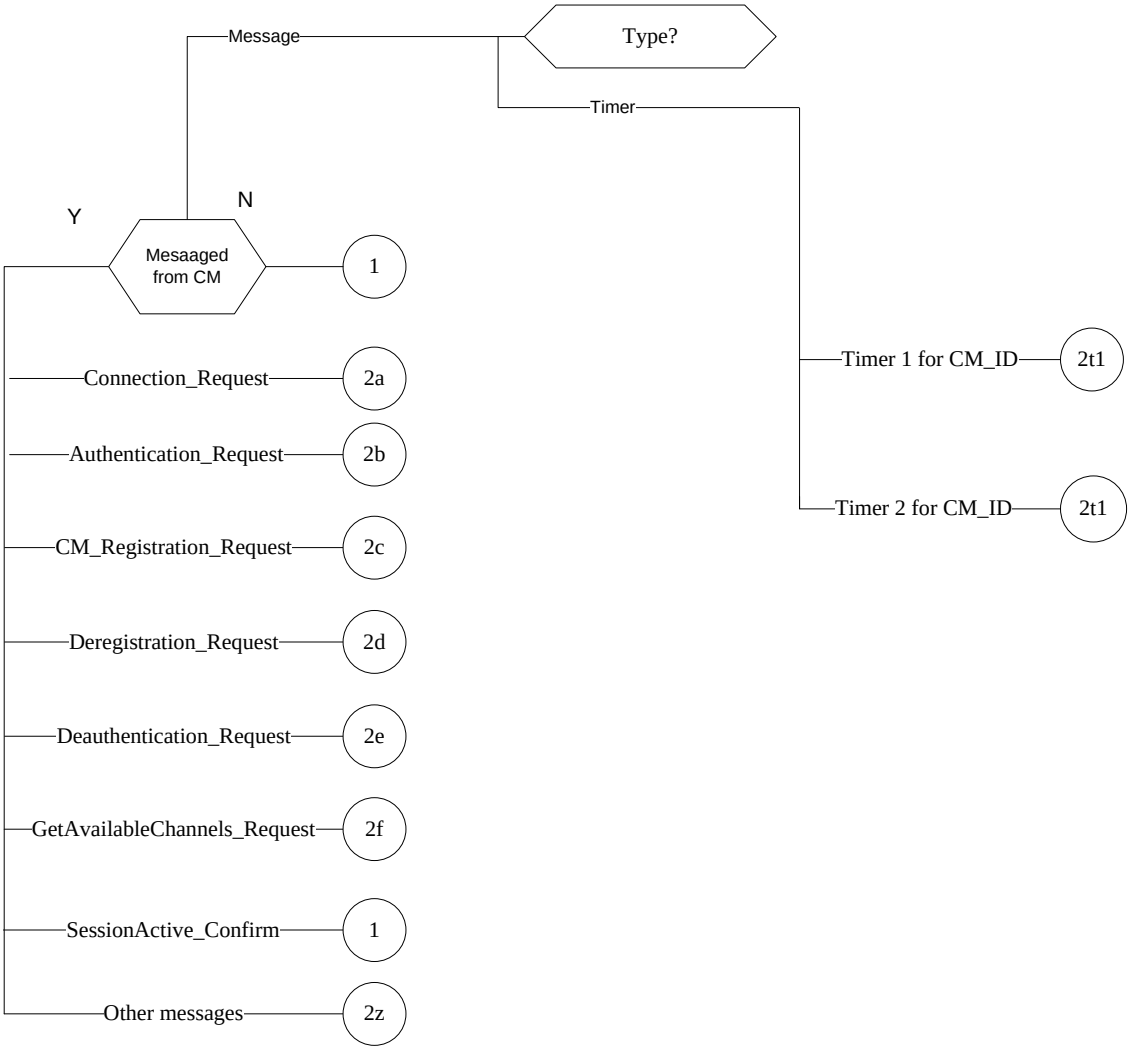


**Figure 39 CDIS operation**

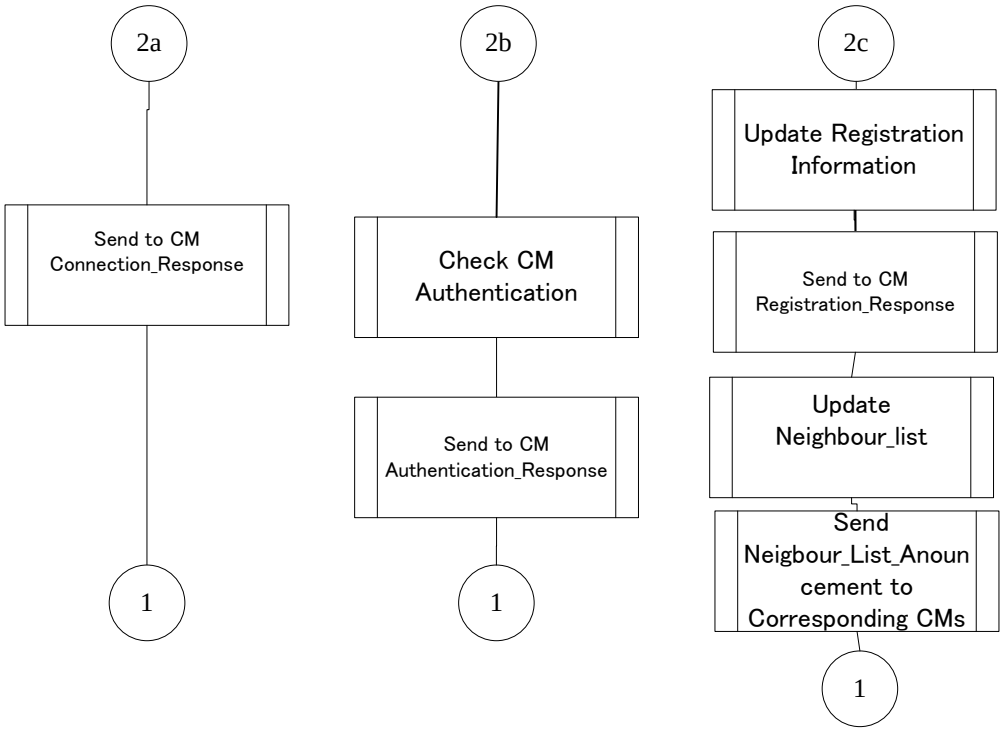


**Figure 40 CDIS operation**

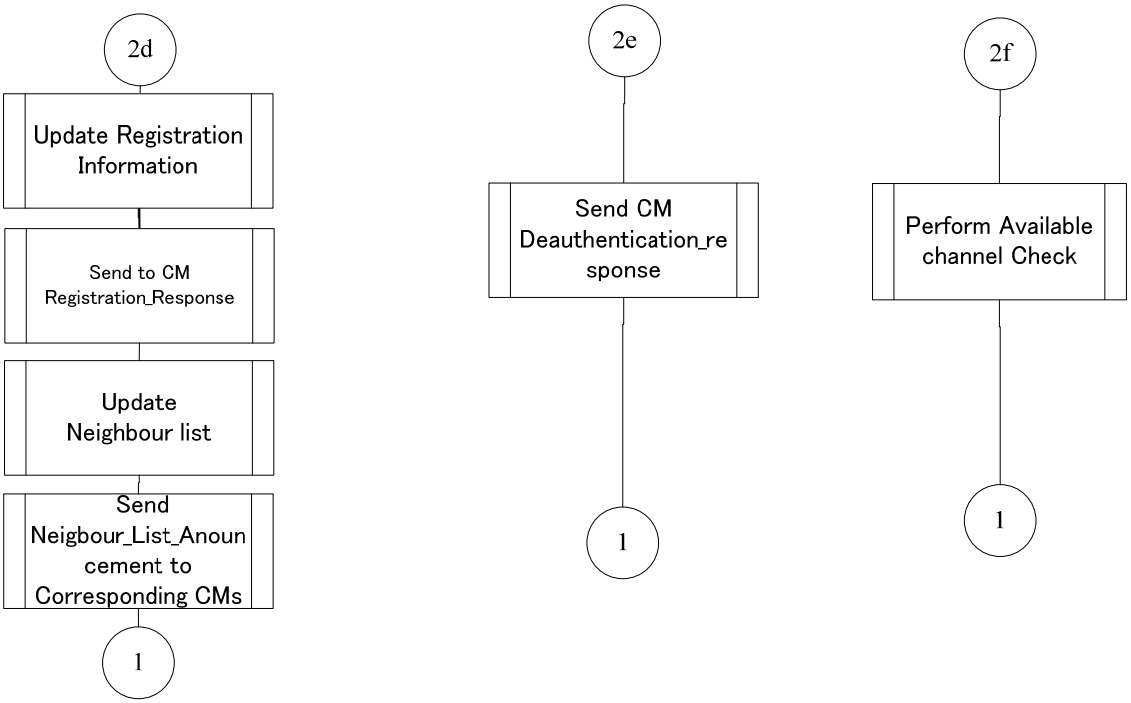


**Figure 41 CDIS operation**

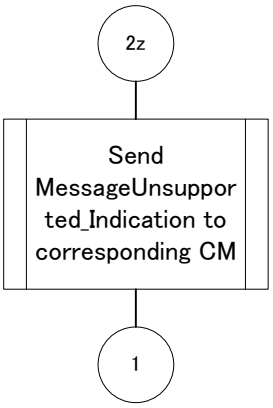


**Figure 42 CDIS operation**

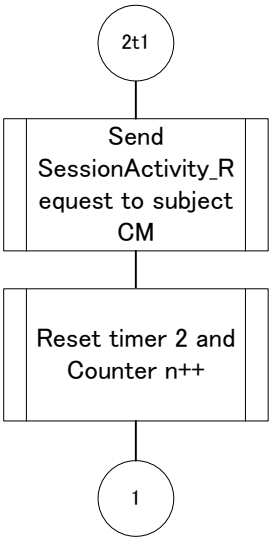


**Figure 43 CDIS operation**

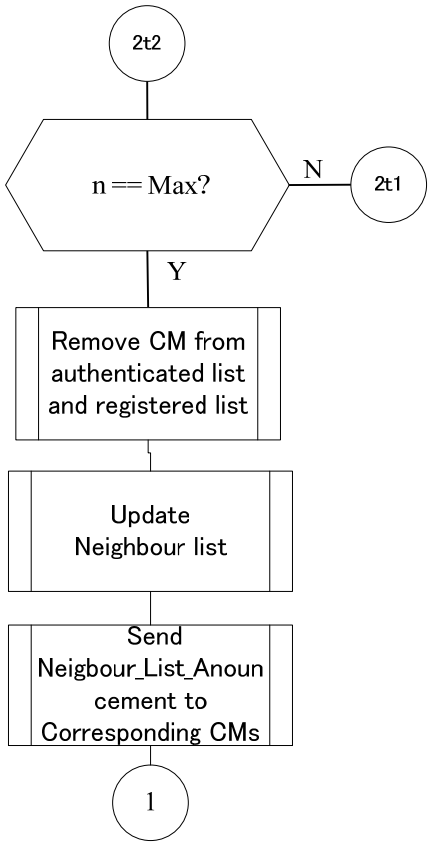


**Figure 44 CDIS operation**